Urban Public Transportation Systems

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Proceedings of the
3rd International
Conference on
Urban Public
Transportation Systems

ASCE

Edited by
Steven L. Jones Jr., Ph.D.

TRANSPORTATION
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URBAN PUBLIC TRANSPORTATION SYSTEMS 2013

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Preface

The Third International Conference on Urban Public Transportation Systems was held at the prestigious Conservatoire National des Arts et Métiers (CNAM), in Paris France, on November 17-20, 2013. The conference follows a tradition of workshops and conferences sponsored by the American Society of Engineers (ASCE) intended to address themes related to improving mobility, accessibility and, ultimately, quality of life through advances in the field of transportation systems. The First International Conference on Urban Public Transportation Systems was held in Miami, Florida, during March 21-25, 1999 and the second on was held April 14-18, 2002 in Alexandria, Virginia.

The Third International Conference on Urban Public Transportation Systems was sponsored by the Public Transportation Committee (PTC) of the ASCE Transportation and Development Institute. The conference proceedings represent state-of-the-art and practice papers covering the following topics:

- Planning, Environment, and Finance
- Operations & Maintenance
- Infrastructure and Design
- Innovative Systems and Practices

The review process for conference papers began with a call for abstracts. Following their review, draft papers were submitted and reviewed by an international pool of reviewers from academia, private industry and public organizations. In all, 75 papers were reviewed by an international pool of reviewers from academia, private industry and public organizations. Where necessary, some papers underwent a second review and revision process. The final product of the efforts of all involved is this set of conference proceedings comprising 41 peer-reviewed conference papers.

On behalf of the conference organizers at-large and the PTC, we wish to thank all of the authors, presenters, session chairs, reviewers and the ASCE staff and consultants that made this conference and these proceedings possible. Particular gratitude is extended to Debby Tucker and Patrick Driscoll for assistance with the paper management system and their patience and flexibility throughout the process. Finally, we would like to dedicate these Proceedings to the life and work of Jean-Claude Ziv.

Steven L Jones, Jr., Ph.D., *Conference Co-Chair and Proceedings Editor*
Walter Kulyk, P.E., *Conference Chair*
Murthy Bondada, Ph.D., P.E., *Honorary Conference Chair*

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PRT mode share estimations using a direct demand stated preference method

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ABSTRACT

Contrary to the widespread assumption that car use is inflexible, we find that a vast majority of the population are in fact ready to change to public transport (PT), if its service characteristics feature an easily accessible, clean, frequent transport without transfers and with seated comfort – characteristics that have proven impossible to satisfy with conventional collective transport. Personal Rapid Transit (PRT) can provide all of these features. In the BICY project, our direct-demand estimate finds that PRT share would become dominant after the provision of a citywide PRT network, and that more than half of the 10 cities, private transport (car and motorcycle) would drop below 15%. We also find PRT ridership will depend strongly on the level of present PT usage. This confirms previous findings of studies on PRT mode shares. The difference is that the present study, using direct demand estimation, shows generally higher PRT (equals PT) shares.

1. INTRODUCTION

PRT is an emerging transport technology, based on small-size, fully automated electric vehicles (see Figure 1). With PRT, up to 6 passengers travel together, by choice; vehicles can be made available on demand and 24h a day; the trip is non-stop to any station connected to the network; and passengers travel both in seated comfort and in a private atmosphere. PRT requires new infrastructure to be installed: PRT guideways are grade separated, which means that they are either elevated, underground or on dedicated on-ground corridors. Guideway dimensions are slim (typically 1.4m width). The most advanced existing systems are**:** *ULTra*, in public operation at London's Heathrow airport (ULTra, 2010); *2getthere*, with a circuit in public operation at the sustainable city of Masdar, Abu Dhabi (2getthere, 2010); and *Vectus PRT* with a full-scale test track in Uppsala, Sweden and an additional system under construction in Suncheon, South Korea (Vectus 2010).

Because only a few, small-scale PRT networks exist at this time, generating ridership estimates faces the "chicken-and-egg" problem, in that a survey respondent is not able to refer to experience when asked whether she/he would choose a future PRT system instead of a car. This lack of experience has frequently prevented a proper calibration of mode share models. Mode share models allow determination of prospective future shares of ridership for all available modes, given a specific scenario. Usually the shares are a function of trip times, trip costs and a mode-specific constant, MSC (also known as mode-specific “convenience”).

Attempts to include PRT in mode share models have been limited in the past. In 1978, Ed Anderson proposed a Logit-type mode share model for PRT ridership estimation. He also showed that the probability to choose PRT increases with station density (or network coverage). However, the PRT share was estimated using public transport mode share models where the MSC was calibrated on the characteristics of bus and car offers. Nevertheless, studies examining several Swedish cities using Anderson’s modeling technique showed that public transport ridership would almost double using a PRT network instead of bus/tram lines.

The first utilization of stated preference interviews to model PRT was conducted within the EDICT project (EDICT 2004), where a large increase in PT share was also projected, confirming the Swedish findings.

ULTra PRT 2getthere Vectus PRT

Figure 1. The three most advanced PRT systems.

In the BICY project, our direct-demand estimate has been used to analyse general mobility behavior, which allows new findings for PRT. In this process we generated mode share estimates from the BICY project and compared it with previous findings, validating the survey methodology. These results combine well with the stated preferences of survey respondents, to estimate mode share given a PRT scenario. A fundamental problem has been to quantify the increase in PT mode share after the installation of a PRT service. In Europe, larger cities achieve a PT mode share of 25-45% in city centers and 20%-30% in larger urban areas. However, in smaller cities the mode share of PT is often much lower. PRT may offer a strategy to increase the PT share as PRT could potentially attract many automobile users due to its high service quality. At the same time, unlike motorized personal transport as well as buses and surface level trains and trams, PRT would not conflict with other more sustainable modes such as cycling and walking because of its grade-separated guideways.
Section 2 explains the methodology of the survey, and the results are presented and discussed in Section 3, while Section 4 draws the conclusion.

2. METHODOLOGY

As part of the Central Europe project BICY, street surveys have been conducted in 10 cities, located in seven central European countries: Ferrara (FE), Comacchio (CO) and Ravenna (RA) in Italy; Graz (GR) in Austria; Košice (K), Michalovce (MI) and Spišská Nová Ves (SNV) in Slovakia; Prague (P) in the Czech Republic; and both Koper (KO) and Velenje (VE) in Slovenia. This survey collected data about the present use of transport modes, and under which conditions interviewees would change from car and motorcycle use, to PT and/or bicycle use.

As a first step, the current modal split has been determined for each city. By modal split we mean the share of regular trips performed by each mode. The modal split has been calculated in the following way: the questionnaire contained a table aimed at gathering information about modes, frequency of usage and trip purpose, see Figure 2. The currently used mode has been the mode used every. In cases where two or more modes have been indicated for everyday's usage then the mode associated with the longest daily distance has been selected. For this reason, there has been an additional table where the interviewee has indicated how much time she/he spends for each mode on a regular workday. From the time information the daily distance per mode has been estimated, assuming average urban speeds for each mode.

How often do you use ...			Motivation	
	almost every day		work/study	
	from time to time		shopping	
	never		other	
	almost every day		work/study	
	from time to time		shopping	
	never		other	
	almost every day		work/study	
	once in a while		shopping	
	never		other	
	almost every day		work/study	
	once in a while		shopping	
	never		other	

Figure 2. Part of the survey to ask for transport mode and trip purpose.

The street surveys are not perfectly representative, even though representative groups such as supermarkets and schools have been targeted for the interviews. Statistical corrections have been performed by applying relative weights to interviewees belonging to different groups (males, females, minors, adults, seniors, and car owners. Additionally we validated our modal split results through comparison with others' findings or by "reality check" where no alternative source for modal split was available. The surveys of three cities (not included here) were rejected either because some groups were not represented or because the model split was not deemed realistic.

Once the currently used mode was established, we wanted to know how many of those who currently do not use PT would use PT on a regular basis, in a scenario where the PT would provide certain features. In particular we asked: "What are the *minimum requirements* that would *convince* you to use PT for your daily trips?"

The interviewees could define their set of requirements by selecting one or more out of five required characteristics (R_m) from the following list:

R_1: "the stops or stations can be easily reached on foot (in less than 5 minutes)"
R_2: "buses, trams or rail are always clean and have air-conditioning when needed"
R_3: "waiting time is never more than 5 min at a stop or station"
R_4: "direct connection, no transfers"
R_5: "there is always a place to sit"

Alternatively, interviewees could choose: "under no circumstances I would make regular use of public transport". This answer would cancel all previously stated requirements. Further, if no R_m requirements were given, we assumed that the interviewee is not inclined to change to PT.

Next we find out the relation between PT service characteristics and the share of users who would switch to PT, if certain characteristics were provided. We have defined five scenarios (PT_j), where each scenario represents a PT service offer, defined through a set of characteristics that the offer satisfies:

- Scenario PT_1 is an area covering network that satisfies only requirement R_1. Scenario PT_2 assumes the same area covering network, *and* clean and air-conditioned vehicles (thus R_1 and R_2 are both satisfied).
- Scenario PT_3 satisfies the requirements of PT_2 *and* includes R_3, hence waiting times are less than 5min across the network. (Scenario PT_3 can be considered a best case traditional, line-oriented PT.)
- Scenario PT_4 satisfies R_1, R_2, R_3 and R_4. This is Scenario PT_3, but without any transfer between any stations. These characteristics can only be satisfied by an on-demand type service, for example a "call-a-bus" where origins and destinations are booked in advance.
- Scenario PT_5 satisfies *all the requirements,* R_1, R_2, R_3, R_4 and R_5; which means that it also offers a guaranteed place to sit. The service assumed in PT_5 is *de facto* either an on-demand taxi service, or a PRT network. But it is worth noting that PRT has never been mentioned to the interviewee. This suggests when answering the questions, the interviewee has been thinking about an ideal bus, train or tram system rather than a completely different transport mode, like PRT.

For the estimation of the PT mode share produced by each scenario PT_j, we have applied the following algorithm: for each interviewee, his/her PT characteristics that he/she requires for a mode-change have been compared with the characteristics provided in the given scenario. If all of the respondent's stated requirements are provided by the scenario, *and* the respondent did not negate the possibility of using public transport, then and only then is the interviewee expected to switch to PT. Otherwise, the respective interviewee is expected to continue to use the present mode. It is further assumed that those who already use PT on a regular basis will continue to use PT. With this procedure we obtained a "stated" modal split for each PT scenario, and thus a relation between PT characteristics and PT mode share. Note that any scenario

PT_j needs to satisfy the associated characteristics in all parts of the city.

4. MAIN RESULTS AND DISCUSSION

The mode shares obtained from the survey are shown in Figure 3. Note that all Slovakian cities (Košice, Michalovce, SNV) have a higher PT share than similar Italian and Austrian cities. Prague has an even higher PT share, but as stated previously, larger cities do have a higher PT share as they typically have a more dense PT network. The Slovenian cities of Koper and Velenje have a modal split similar to Western European cities. This result is in line with car ownership in Slovenia, which is similar to Western European levels.

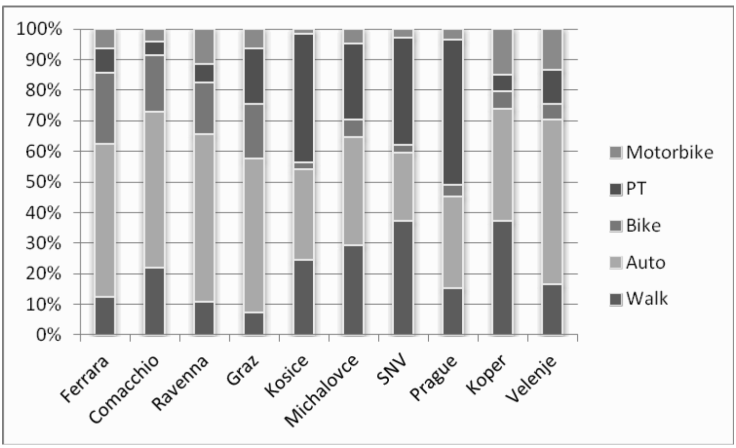

Figure 3. Current modal split as obtained for 10 of the surveyed cities.

Next we discuss the results of the stated PT share for scenarios PT_1 through PT_5. Figures 4 and 5 show the results for Western and Eastern European countries, respectively. Almost all cities have in common that the PT share of scenario PT_1 and PT_2 remains practically the same as current levels. This means the requirements satisfied by PT_1 and PT_2 (nearby stations and clean vehicles) cannot convince many to change to public transport. The exceptions were Ferrara and Comacchio, where additional stops and cleaner vehicles could attract more passengers.

If a citywide PT network would guarantee 5 minutes maximum waiting time, the survey suggests that this would increase PT share by approximately an additional 10% on average (see scenario PT_3). In absolute terms, these are PT mode shares jumping to between 20%-45%, depending on the current mode share. An exception is Graz, which remains fairly flat through PT_3, suggesting there is already a high level of transit service.

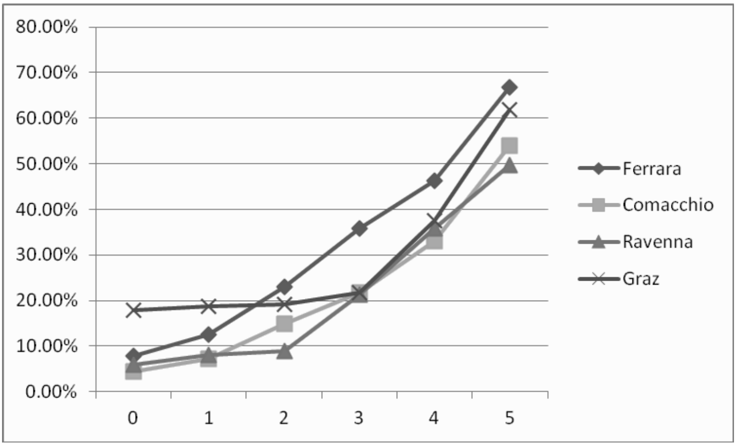

Figure 4. PT mode share for current situation (at x=0) and stated PT mode share for public transport scenarios (PT_1-PT_5) in Western European cities.

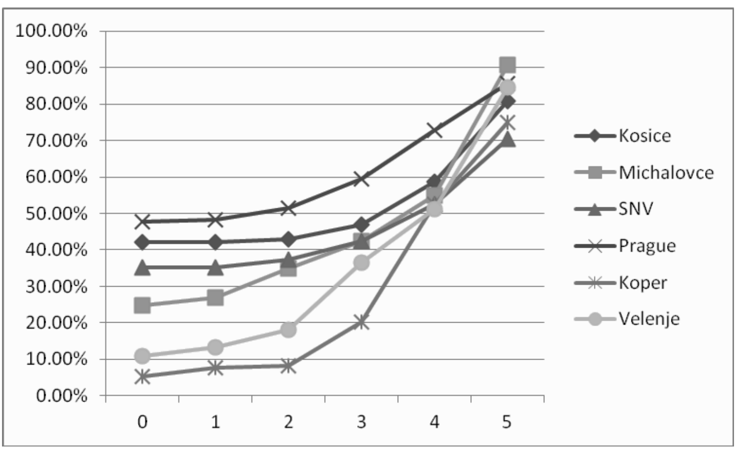

Figure 5. PT mode share for current situation (at x=0) and stated PT mode share for public transport scenarios (PT_1-PT_5) in the Eastern European cities.

Finally, the additional requirements in scenarios PT_4 and PT_5 are those that would most dramatically increase the PT share – namely, the provision of a citywide network where all destinations can be reached without transfers and always in seated comfort. It is worth noting the main difference between Western and Eastern European cities: the eastern cities reach consistently higher PT mode-shares than western cities. This is true even if cities had similar current PT mode shares: for example, comparing Ravenna with Koper, Ferrara with Velenje, or Graz with Michalovce, we see that the eastern cities show a higher PT shares for scenario PT_5.

Focusing on scenario PT_5 we can state that the requirements cannot be satisfied by line-oriented collective transport. In fact, this level of service can only be satisfied either by a well-organized and high volume taxi service, or by an area-wide Personal Rapid Transit (PRT) network.

The survey did not ask how much the user is ready to pay for the requested PT service. This means a taxi-service with a much higher price-level than current PT fares is unlikely to attract more demand as it does today. However, if a PRT service was offered at prices similar to current PT fares and if there were no additional congestion-related delays (for example, queues at PRT stations), the present survey predicts a significant modal shift to public transport. The scale of such a modal shift can be seen by comparing Figure 6, showing the current modal split for PT and individual transport (IT = mode share of car + Motorbikes) with Figure 7 showing the modal split of PT scenario PT_5.

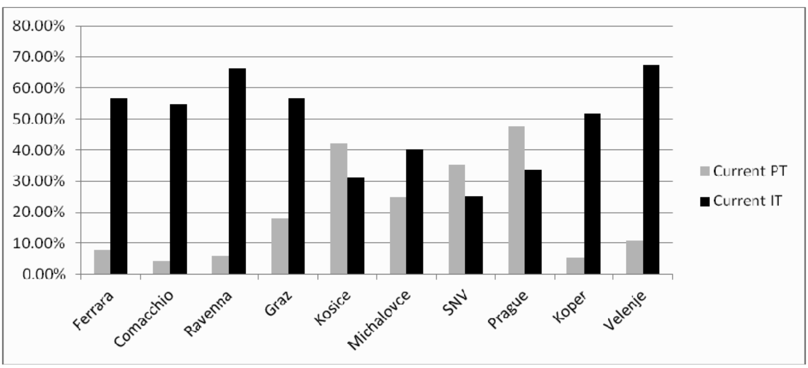

Figure 6. Comparison of current PT mode share and current Individual Transport (IT) mode share for all surveyed cities.

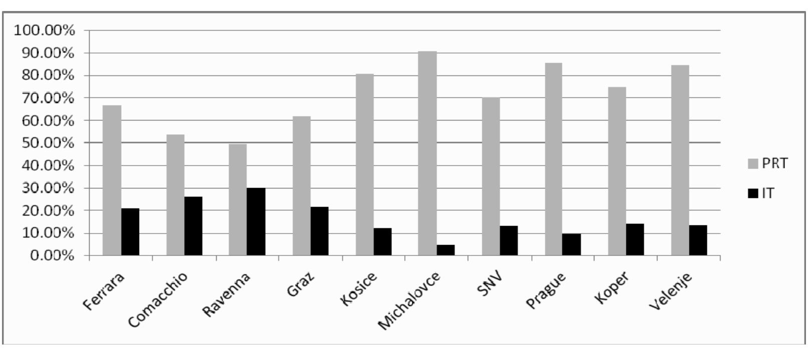

Figure 7. Comparison of stated PT mode share of PT scenario PT_5 (PRT scenario) and Individual Transport (IT) mode share for all surveyed cities.

It can be seen that the share of PT in the PRT scenario becomes dominant in all cities. Individual transport (IT) becomes almost marginalized in Eastern European countries.

As promising as this appears, it is important to address the limitations of stated preference surveys, as the results are based on some naive assumptions: it is by no means certain whether people who claimed they would change to PT while compiling the questionnaire, will eventually do so once all their stated PT requirements are met. Yet people have been asked questions about realities that almost everybody has already experienced (we did not asked if they prefer to ride a PRT), strengthening the likelihood that respondents were sure of their replies. Further, the survey first asks detailed time estimates for all regular travel, so respondents have already recalled and quantified their daily travel times before considering PT preferences.

Another assumption has been that PRT will have fares similar to current PT and that the PRT network has the capacity to cope with the generated flows. The PRT systems on the market (see Figure 1) may not have the required capacity for a widespread urban application and are currently likely to be more expensive than an urban bus.

There is also a secondary effect to consider: even if a citywide PRT network with grade-separated guideways were installed, and a noticeable modal shift towards PRT had taken place, the public would experience less traffic congestion on the road network and it would be more attractive to return to use the car. To prevent this secondary effect, the introduction of any PRT network should be accompanied with measures to reduce road space (conversion to green space, cycle tracks, etc.).

In its further defence, PRT promises even more key characteristics than were represented in the survey: 1. PRT allows travel in a private space without having to share with strangers; 2. The service is available 24 hours a day, on demand. These features could convince even more people, and even further increase PT mode share.

5. CONCLUSION

A stated preference survey has been conducted in ten central European cities in order to quantify the mode share of public transport (PT) as a function of PT service characteristics.

The maximum share of Personal Rapid Transport (PRT) ridership achievable based on respondent preferences depends strongly on the present level of PT usage: a high present PT results in a high potential share of PRT ridership, if a PRT system were to be introduced. This confirms previous findings on potential PRT mode shares. The difference is that the present study, using direct demand estimation, predicts substantially higher PRT shares.

In the BICY project, our direct-demand estimate finds that PRT share would become dominant after the provision of a citywide PRT network, and that in more than half of the 10 cities, private transport (car and motorcycle) would drop below 15%.

A secondary finding is: even if all PT services had the service characteristics of a state of the art public transport, the PT mode share would remain within the limits of best practice cities in Europe. In contrast, if a comparably-priced PRT system were to provide citywide service, the PT mode share should see significant increases and become the dominant mode. In all surveyed Eastern European cities, car trips would become insignificant. For policymakers hoping to improve the sustainability of the transport system, major investments in PRT systems deserve further review.

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PRT as a supplement to existing transportation modes

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ABSTRACT

Personal Rapid Transit (PRT) is a mode designed to increase the service level of public transport so as to approach that of taxi and private cars. The PRT systems in public service today are stand-alone systems within confined areas with no other public transportation. This paper describes potential applications where PRT is an integrated part of the public transportation supplementing and supporting the existing transportation modes.

Most cities already have public transport and it will be some time before PRT alone can serve travel demand in a large area. One of the roles in which PRT can supplement existing transport is as a feeder/distributor to commuter rail, subway and light rail.

Application cases of PRT and mass transit are discussed based on studies using the "PRTsim" software.

MASS TRANSIT AND PRT

Most cities have conventional transit modes such as trains, metro, light rail and bus. These modes all serve fixed routes by fixed timetables. Transit has not been very successful in competing with private cars. Transit mode share is less than 5 % in the US and about 25 % in Sweden.

Personal Rapid Transit or Podcars are designed to offer important qualities of private cars, in order to reduce road congestion by increasing the use of transit:

- Departure on demand – none or very short waiting
- Direct and non-stop trips – no transfers within the PRT network
- Travel in privacy or with chosen company
- Driverless operation – allows 24/7 service at low cost

APPLICATIONS FOR PRT

Morgantown PRT in WestVirginia USA has been in operation during more than 35 years. It is driverless and operating on demand with off-line stations. Compared to modern PRT, Morgantown vehicles are relatively large (8 seats plus standees) and at certain times running on schedule. Modern PRT systems operate at Heathrow airport and Masdar City in Abu Dhabi. New PRT systems are being built in Suncheon South Korea and Amritsar India.

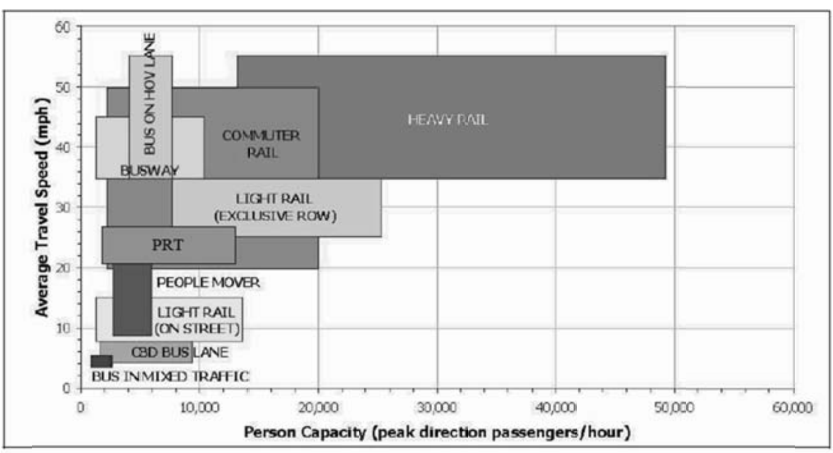
Feasible future PRT applications include:

- Airports
- Campus sites
- Shopping areas
- Theme parks
- Connectors between transit corridors
- Supplement to bus routes
- Feeder/distributors to mass transit
- Local transit in cities

This paper discusses various applications for PRT where the author has been involved in transport modeling using the "PRTsim" software.

CAPACITY AND SPEED COMPARISONS

The diagram of figure 1 illustrates line capacity and speed range of various transit modes. The capacity of PRT is higher than that of bus even with dedicated bus-lanes or bus-ways.



Sources: "Transit Capacity and Quality of Service Manual," 2nd Ed.- TCRP
PRT – J. Edward Anderson

Figure 1. Capacity and speed of conventional transit and PRT

PRT and light rail on street offer similar capacities. This may surprise some since PRT vehicles are small (typically 3-6 passengers). The explanation is that PRT vehicles can run at headways as short as 2-3 seconds. Beyond line capacity PRT offers additional capacity through alternative routings in a PRT network.

Travel speed of PRT is superior to that of bus in mixed traffic and on bus-lanes. The two main reasons for higher speed are

1) separation from other traffic and

2) no stopping from origin to destination.

PRT travel speed is also higher than that of light rail on street.

The high performance of PRT is not a reason for PRT to replace existing transit infrastructure. Rail-based modes represent large previous investments and where they exist they should continue to be the backbones of transit.

This paper presents ways for PRT to supplement conventional transit to make the total transit offering more competitive and appealing.

PRT AROUND AIRPORTS

Airports are primarily intermodal transport nodes between air, road and transit. Areas surrounding airports are hot for development for parking, car rentals, hotels, business, offices, entertainment and more. Good local mobility – not only by car - will support such development.

PRT serves well as a connector between modes and activities. Fast and convenient travel on demand with chosen company offers important qualities, making the airport area accessible and attractive.

The land surrounding an airport often has a single owner/authority who can decide about its use and accessibility. This is in contrast with urban areas where decision-making is political and new infrastructure gets challenged by citizens. In contrast, airport development can be a commercial decision by a single authority, which tends to shorten the decision and planning processes.

Airports may decide to offer local transport free of charge since they have other more important revenue streams such as landing fees, business concessions and rents, which all are supported by good local transportation.

Figure 2 shows a possible PRT system around Mineta Airport in San José, CA.

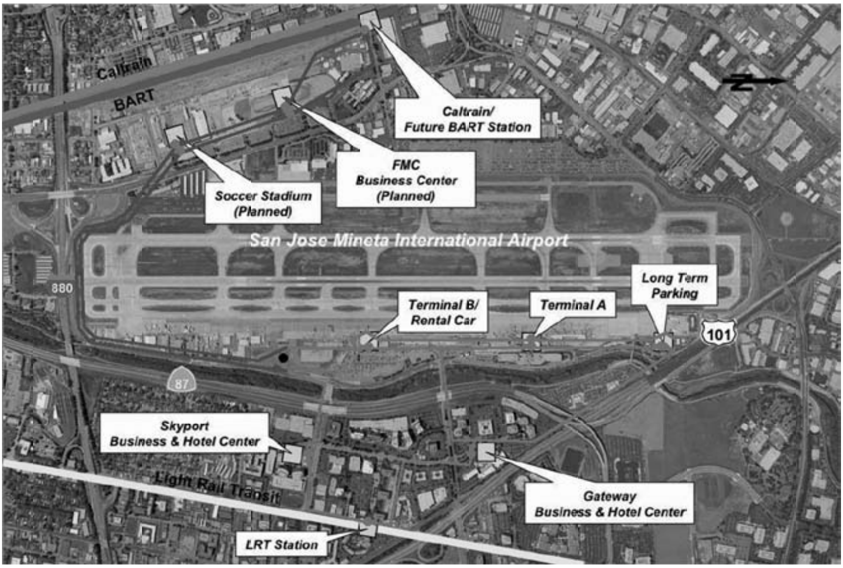


Figure 2. Mineta airport with mass transit lines and a possible PRT system in two stages (red and blue).

PRT IN CAMPUS AREAS

A University campus is also a good site to introduce innovative transit. Students are early adopters, quick learners and future decision-makers. It is a further advantage if students can get used to going by without a car. As for airports a campus may have one owner of the real estate who can make his own decisions and no permanent inhabitants who might object to new infrastructure.

Figure 3 illustrates three university campuses in Stockholm, Sweden all with the same real-estate owner/developer (Andreasson 2009). The central hub area (circled) is being developed for joint use by all three universities. The PRT system would also connect the hub with two Metro stations (marked by T) providing transit access to the new development.

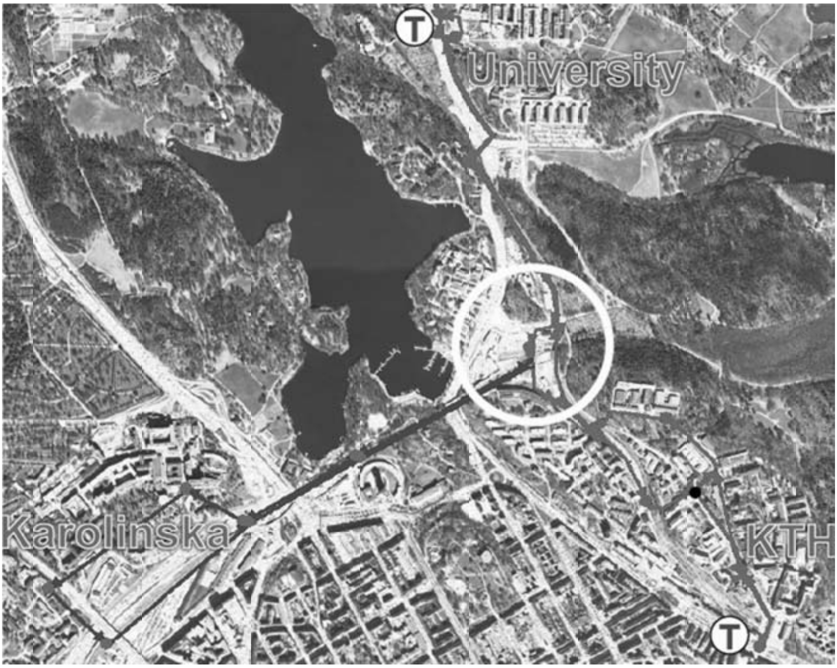


Figure 3. Proposed PRT system connecting three university campuses in Stockholm (second stage in blue).

PRT FOR SHOPPING AREAS

Many shopping areas consist of huge parking areas with shops spaced too far apart for walking from one shop to another. One of them is Kungens Kurva south of Stockholm City with Sweden's largest Ikea store. Transit access is poor with the area separated from a Metro station by a 6-lane motorway. 95 % of all visitors come by private car.

An study (Tegnér 1995) as part of the EU-funded EDICT project analyzed effects of the local PRT system of figure 4 combined with suggested parking structures at the two entrances to the area. Transit visitors were estimated to increase from 5 to 20 %, car traffic would decrease by 9 % while total visitors would increase by 17 %.

In this case PRT serves as an extension of the Metro making the shopping area accessible by transit.

Many shopping areas like this one would benefit from remote parking with a local circulator. Freeing parking space would allow dense and walkable development in former parking areas.

Figure 4. PRT network for shopping area. Metro station (T) and area entrance parking (P). Possible extension blue.

PRT FOR THEME PARKS

Most theme parks are not accessible by car and are often too large for walking. The PRT system of figure 5 would improve transit access by connecting to a Bus Rapid Transit stop at the northern entrance and also be an additional attraction in itself.

Figure 5. Proposed PRT system for Guadalajara Zoo.

PRT CONNECTING MASS TRANSIT CORRIDORS

Many cities have radial services by commuter rail and light rail between suburbs and the city center. Figure 6a illustrates an example from Gothenburg with existing rail lines (black) in the early 1990:ies. A People Mover ring (red) was proposed to interconnect the radial routes.

83 % of all passengers on this 7-station ring would need to transfer from/to tram or bus. A larger PRT system (figure 6b) at the same investment cost was estimated to attract 67 % more passengers, and thanks to more stations and better coverage only 40 % would need to transfer (Blide 1994).

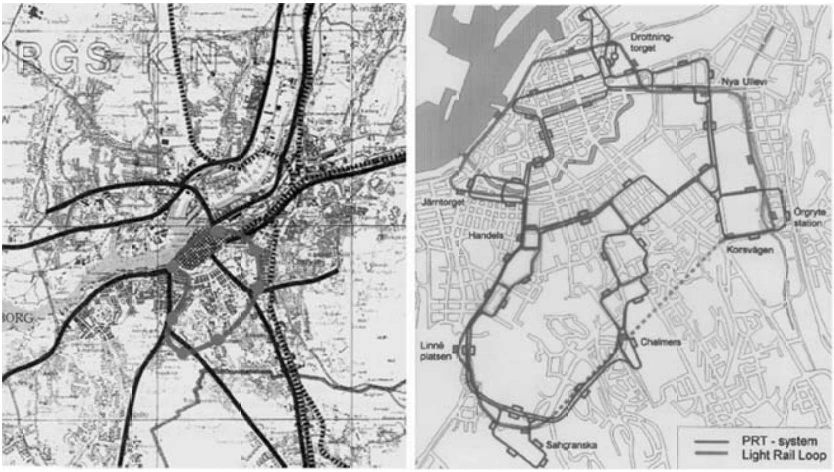


Figure 6 a. 1992 plans for a connecting ring (red) between rail lines (black) in central Gothenburg. b. Alternative PRT (red) and LRT (green) systems.

PRT SUPPLEMENTING BUS ROUTES

The university and hospital area of Swedish Umeå is not well served by buses, see figure 7 in the southeast corner. The same is true for the airport in the very south. These areas were suggested for a first phase PRT introduction.

Total transit ridership on bus and PRT was estimated to increase by 31 % by the introduction of PRT in that area (Andreasson 2011). The new passengers were attracted by the improved service within the PRT network. Even though buses lost passengers within the PRT network (figure 7b), bus ridership was estimated to increase by 20 % thanks to new transit passengers transferring to and from PRT. The added attractiveness of the total transit system made more people leave the private car.

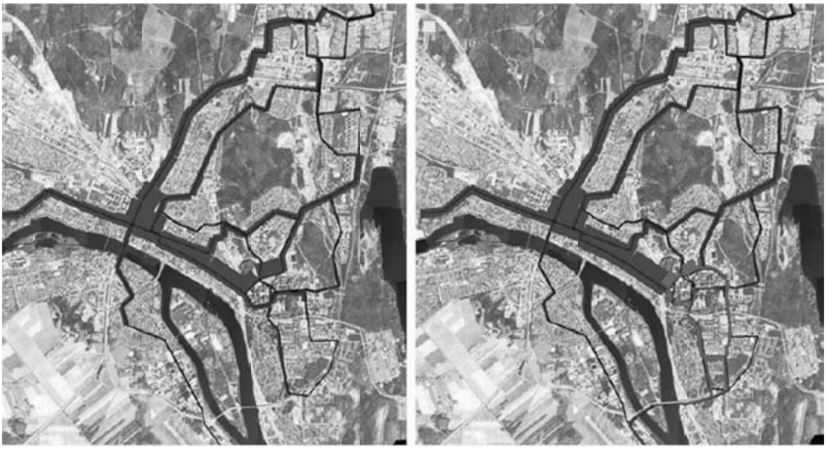


Figure 7a and b. Bus (blue) and PRT (red) passenger flows before and after PRT.

PRT AS FEEDER / DISTRIBUTOR TO RAIL STATIONS

The most common type of PRT applications studied in Sweden is a medium-sized city with a commuter train station. In the case of Upplands Väsby congestion, noise and pollution caused by diesel buses is a problem. The PRT network of figure 8 was designed for local circulation and feeding/distribution to the commuter train station (Külper 2011). Access time (walk + wait + ride) to the train station is illustrated in figure 9. Acceptable walking distance was assumed to be 400 meter. Only trips starting from violet and red areas need more than 20 minutes door-to-door to the station.

With this PRT system transit ridership was estimated to increase by 19 % during the peak hours and by 46 % during off-peak hours. PRT would offer trips on demand at any time while bus service frequency is reduced in evenings and non-existent at night.

Figure 8. Proposed PRT network for Upplands Väsby.

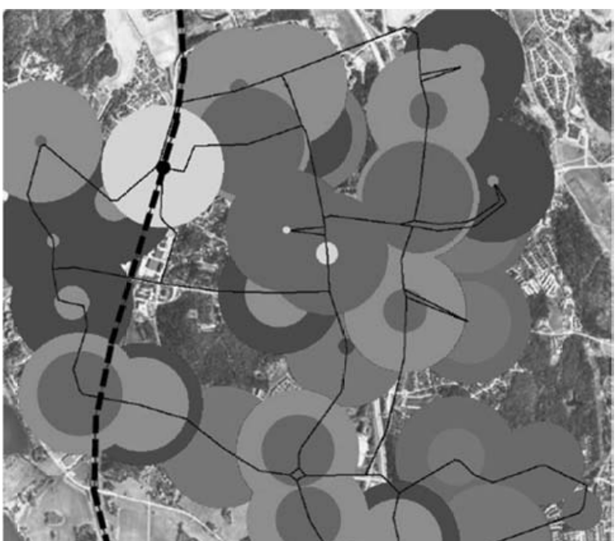


Figure 9. Access time to train station within 5, 10, 15, 20, 25 and 30 mins.

PRT FOR LOCAL TRANSIT

We do not expect to see PRT as the only local transit system in the near future. Nevertheless such a final stage scenario was analyzed for the Swedish city of Södertälje (Andreasson 2008), figure 10. With 43 kms of guideway, 55 stations and 650 vehicles, transit ridership was estimated to triple. The total cost per passenger trip including capital would be 50-70 % lower than the present cost per bus passenger.

Figure 10. Transit travel demand (yellow), trip ends (blue) and passenger travel flows (red) during the morning peak.

MODE COMPARISONS

The focus of this paper is supplementary roles for PRT together with existing modes. It is not an object to compare the various transit modes. But why supplement existing modes with PRT if it does not bring any advantages?

The following advantages in relation to existing transit modes have been identified in a number of PRT studies:

- None, or only short waiting (departure on demand)
- Typically half the travel time of scheduled transit (no stopping)
- No transfers within the PRT network (individual routing)
- Capacity as high as light rail (short headways)
- Investment 50 – 80 % lower than "light" rail (thanks to lower weight)
- Operations cost lower than any other mode (no drivers).

Yet cities continue to invest in light rail while PRT systems remain exceptional. Why may that be?

The main limitations of PRT are:

- Lack of credibility (limited experience)
- Visual intrusion of elevated guideways.

It can therefore be expected that the first few installations will be in airports, campuses, shopping and theme park areas (institutional). No inhabitants to be disturbed and decisions can be made by a single entity. The next level of likely installations is feeder/distributors supporting previous rail investments.

Visual intrusion is an obstacle for any new infrastructure including PRT guideways. As with other transportation infrastructure it will eventually be more acceptable when it has demonstrated its benefit in terms of transport quality.

CONCLUSIONS

- Initial PRT systems will be limited in size and supplementary to existing transport modes

- Several supplementary roles are identified as suitable for PRT

- Early PRT applications are expected to be institutional

- Feeder/distributors can support previous transit investments

- Lack of credibility and visual intrusion are the main hurdles

- Credibility and acceptance are expected to grow with more installations and proven benefits.

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A Comparison of Investment Trends and Economic Development Potential by Public Transport Mode

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ABSTRACT

In response to the severe global economic downturn many nations chose to enact greater investments in public transport. Both the size and nature of these investments varied from country to country, also with varying results. The rationales for these investments also varied, depending on how each country developed its investment program and the rationales for these strategies.

Meanwhile, some countries such as the U.S. have ended these investment increases or even reduced their overall public transport investments levels in response to their growing debt and stagnating economic recovery. Other countries have continued higher levels of public transport expenditures despite budgetary cuts in other programs. Meanwhile, even within the U.S., the levels of public transport investment vary by state and locality, because subsidiary government levels now comprise half or more of total capital investment.

This paper will provide an international comparison of trends in political support for urban transport infrastructure investment, particularly since the onset of the global economic recession.

The rationales for these investments will also be examined, particularly with respect to the mix by mode. In addition, the paper will track how in the U.S. these trends differ by state and locality, reflecting a pattern of regional variance in Europe. The primary difference in the U.S. is that substantial increases in public transport expenditures have been enabled through successful ballot initiatives in the U.S. independent of federal policy changes. Finally, an analysis of the goals and success metrics of these policies will be provided, with implications for future policy directions.

INTRODUCTION

Primarily as a result of the rapid globalization that has occurred throughout the world—with fully more than half of all people now living in cities—public transport investment has increased substantially. Accordingly, cities have continued to increase their investments in all modes of public transport, including bus networks, intercity rail lines, regional rail systems, bus rapid transit (BRT), light rail transit (LRT), streetcars (also known as trams outside North America) and metros (known as heavy rail in the U.S. and Canada).

With the global financial collapse of 2008 and the ensuing deep recession, most countries responded with an initial fiscal stimulus to arrest the collapsing economic situation. Much of this comprised additional infrastructure spending, including in public transport.

However, concerns regarding the levels of public debt governments were taking on, particularly in developed countries, began to overtake concerns about the need for greater investments in infrastructure. Beginning with 2011, the governments of most developed economies had ended their fiscal stimulus programs, and with some exceptions, also ended or substantially reduced their increases in public transport investments.

Meanwhile, the patterns of such investments, whether during the height of the additional period of stimulus, or before or after, continue to differ by the state of economic development and by regions. Part of these differences can be explained by historical bias in favor of road-based programs, while part can also be explained by the ability of governments to afford various investment choices.

For example, in the developing world, a greater emphasis has been placed on BRT investments. Indeed, some of the more famous examples of the mode have occurred in such places as Curitiba, Brazil and Bogota, Columbia. A roster of the cities that are planning or developing their BRT systems compiled by the New York-based nongovernmental organization International Transport Development Program (ITDP) disproportionately includes developing nations.

This is not to say that BRT remains largely the province of the developing world; far from it. In fact, interest in the mode has rapidly spread to virtually every developed economy as well.

At the same time, virtually every developed nation has increased its investments in rail-based systems. Many developing countries, including those in China, the Middle East, Asia and Latin America, have also increased rail investments to cope with rapid urbanization. We will look more deeply at the rationales for these investments, particularly recently as the economic crisis has shift to greater concerns over public debt. We will also examine several case studies regarding the economic returns that have ensured by rail-based public transport networks versus BRT systems.

What emerges from this analysis is that while BRT began as a lower-cost and faster-to-develop alternative to most rail-based solutions to growing congestion caused by global urbanization, a growing body of evidence suggests that the perceived gap in economic return on these investments between that generated by rail systems compared with BRT may not be as great as originally believed. This could have enormous implications for local and national policy makers, which will be discussed subsequently.

ECONOMIC RETURNS OR MOBILITY?

The rationales for public transport investment boil down to two fundamental issues: the primary rationale being a solution to the need for greater mobility, particularly to relieve traffic congestion or achieve greater travel efficiency or connectivity from point to point; the other justification is as a mechanism to gain or enable greater economic development. Virtually all projects offer up these rationales, but the emphasis on them may differ from city to city or nation to nation, depending on national or local political and economic circumstances. They also differ depending on the mode being promoted.

Ultimately, however, the answer to the question “Economic returns or mobility?” as not been “either/or” but rather “both.”

Outside the U.S., these concerns center around the concept of sustainable development, wherein transport project objectives combine or at least balance these dual needs. Perhaps the most illustrative recent developments of this thinking is the announcement by delegates to the United Nations’ Rio+20 summit this past June. There, during the Sustainable Development Conference in Rio de Janeiro (Rio+20), the world’s major nongovernmental lending institutions—including the African Development Bank, Asian Development Bank, CAF-Development Bank of Latin America, the European Bank for Reconstruction and Development, the European Investment Bank, the Inter-American Development Bank, the Islamic Development Bank, and the World Bank— committed to providing more than $175 billion over the next 10 years to support sustainable transport in developing countries.

“This is a game changer for sustainable transport,” said Holger Dalkmann, director of EMBARQ, the World Resources Institute’s center for sustainable transport, regarding the communique. “It will ensure that hundreds of millions of people will have cleaner air, less congested roads, and safer transportation.

“Ten years ago transportation wasn’t even in the discussion; now it’s a major outcome from the world’s preeminent conference on sustainable development.”

The banks’ rationale pointed to the new coordinated effort as needed to address the growing global population (expected to surpass 9 billion by 2050), a majority for the first time in world history now in urban areas, a proportion that is only expected to grow. At the same time, the rate of vehicle ownership is predicted to skyrocket from around 800 million cars a decade ago to around 2 billion in 2030. As a result better urban designs will be imperative, with more sustainable transportation modes, such as walking, biking and using public transport perhaps even more important that the need for cleaner vehicle propulsion technology.

Already, these development banks have contributed billions of U.S. dollars to sustainable transport projects in developing cities. The Inter-American Development Bank and the World Bank have funded BRT projects throughout Latin America, for example. In addition, the Asian Development Bank through its Sustainable Transport Initiative, has undertaken a lending and technical assistance program for transport projects throughout Asia and the Pacific that emphasizes inclusive economic and environmentally sustainable growth.

“Years from now, we may look back at Rio+20 as the moment when transport was pushed to the top of the sustainability agenda,” added Dalkmann.

In the U.S., sustainable development is known as “transit oriented development.” (TOD). It is defined as “…moderate to higher density development, located within an easy walk of a major transit stop, generally with a mix of residential, employment and shopping opportunities designed for pedestrians without excluding the auto. TOD can be new construction or redevelopment,” according to a technical advisory committee to a California statewide study of the subject by the state government's department of transport (known as Caltrans).

"Transit-Oriented Development has the potential to reduce parking per household by approximately 20%," according to another Caltrans study. "TOD commuters typically use transit two to five times more than other commuters," concludes a study funded by the U.S. Federal Transit Administration.

COMPARISONS OF RESULTS BY MODE

How sustainable transport policies are executive often differs by public transport mode. In order to illustrate these differences further, let us begin with the chief characteristics of each mode. With BRT, it has primarily been viewed by policy makers as a less expensive and faster-to-implement strategy for arresting urban congestion than light rail or metros, which take much longer to implement. In addition, BRT was seen as a method to improve the image of bus service, which was viewed by many as inferior to rail based modes; image and identity with BRT are thus valued as more relatively important to the success of the mode than the image and branding of LRT, metros, or streetcars/trams.

While BRT has achieved a level of success in patronage gains that equal or even exceed LRT and streetcar investments, BRT tends to have less of a record of success with respect to economic returns on investment than rail-based modes. This is because return on infrastructure investment tends in large part to be a function of the sense of permanence that give developers confidence. Because BRT projects tend to be less architecturally significant than LRT but similar to streetcars, this typically has meant that rail modes generate more developer interest than LRT, metros or streetcars.

Further, because BRT is more flexible, incorporating more street-running segments than LRT, while streetcars and street running LRT tend to be in reserved rights of way more often than BRT, it is often viewed by developers as more "reversible" than rail modes. This despite the century-long history of cities' ripping out or paving over streetcar tracks throughout the world.

Streetcars generally supplement, but are not directly competitive, or at least typically compared with metros, LRT or BRT as LRT typically is with BRT. Metros are often are typically justified it situations with very high travel densities in a given corridor. Streetcars, on the other hand, typically are best suited for "low speed circulator" applications and can be a powerful urban development tool, as has been proven in Portland, Seattle and Tampa, Florida, or in a variety of situations in Rhine-Ruhr region of Germany.

In the USA, streetcars are often funded locally with business community and developer support. Implementation can be much faster with less cost and lighter intrusion into the streetscape than LRT. Like BRT, streetcars have more potential for incremental implementation due to greater scalability than LRT.

EXAMPLES OF SUSTAINABLE DEVELOPMENT

While any conclusions regarding public transport investments being actual generators of economic development may be in dispute, what is not in dispute is that such economic activity is shaped by the location of public transport investment. At the very least, then, a variety of examples throughput the world demonstrate that economic development and land use can be concentrated around public transport, and as indicated by the above statistics, greater use of more sustainable transport becomes more likely development is coordinated with better land use policy and greater investment in higher quality public transport.

The following examples indicate that both the shape and density of the development is affected by the type of public transport investment chosen. For example, streetcar and tram projects tend to shape development the greatest and is arrayed more longitudinally, closest to rail alignment. In Seattle, USA, the South Lake Union Streetcar generated significant development along its route, a consequence in no small part driven by the local developers in the neighborhoods served by the streetcar as well as the mayor at the time. Both he and a major developer, Vulkan Development Corp., became an influential team in affecting the necessary tax and policy changes to build the project.

Light Rail has significant TOD and sustainable development success, though its development patterns tend to be around its stations, partly due to LRT's greater speeds. In Nottingham, UK, it has helped to catalyze development in the city central business district. In, the Los Angeles region, more than $4 billion in development has centered around the light rail projects built in the county since the early 1990s.

Metros and high-speed rail have perhaps the longest history in generating dramatic results with respect to shaping development. They include the massive mixed-use complexes in cities as diverse as London's Docklands, the developments in Lille, France, Tokyo's Ginza District, Hong Kong and Guangzho in South China and Lower Manhattan in New York.

Until recently, it has been thought by most developers and policy makers that rail projects can generate or shape such development, while BRT is less successful in that regard. Indeed, while BRT has shown throughout the world that it can attract patronage on its systems on the equal of light rail (or even metro systems in the case of some of the South American, Asian and Australian systems), it was thought that rail projects would always be a better strategy for generating and shaping economic returns.

However, recent results have also shown that BRT is also attractive to developers and retailers. Significant examples of TOD generated around BRT include projects in:

- Ottawa, Canada, with billions of dollars invested round stations of its Transitway
- York, Canada Viva, particularly its Markham developments
- Cleveland Health Line
- Boston Silver Line's $1.2 billion in investments from the first phase of the BRT project alone
- Pittsburgh East Busway ($400 million in adjacent development)

- Denver's 16th Street Mall shuttle (which was early BRT before it was called such)
- Curitiba, Brazil Surface Metro
- Bogota, Colombia's TransMilenio

In York, the Viva BRT system has been an important catalyst to the Downtown Markham Development. With a groundbreaking in August 2007, a 243-acre site located within a wealthy suburb of Toronto has attracted 4,000 new condominiums and townhouses, 4.2 million sq. ft of new office space, highlighted by the Simcoe Promenade (higher-density mixed-use zoning along pedestrian-oriented street that will also include new dedicated exclusive bus lanes that comprise Viva's next phase of expansion.

Cleveland is a dramatic answer to those who question whether BRT can generate development. The city's Health Line, so named because it serves the Cleveland Clinic and other world'class health-care institutions along the route, has generated an estimated economic impact of more than $5 billion already, according to the Regional Transportation Authority. By 2025, 7.9 million sq. ft. in commercial development and more than 5,400 new or renovated residential units will be completed along its route. The result will be $62.1 million more in annual local taxes, including $1.98 million in annual sales tax revenues dedicated specifically to the public transport service in the region. More than 13,000 new jobs have already been created as a direct and indirect result of the new BRT system's design and construction, according to the agency.

In cities of developing countries, BRT has also helped to shape land use. However, these projects are also typically combined with auto restriction strategies, such as in Curitiba, Brazil and Bogota, Columbia. In many cases, these auto restrictions are more stringent than similar strategies in developed nations.

In fact, whether rail or BRT projects, this is the most important lessons learned from these examples: land use and transport policy must complement one another. Accordingly officials should establish a planning vision and supporting policies early in the transport project development process. Coordination with all stakeholders in these strategies must also begin very early in the process. These plans must also ensure that projects are designed for the additional pedestrians that will use these new networks, which means that safe pedestrian crossings must be incorporated in project designs. Increasingly, in cities as diverse as Paris, New York and Bogota, facilities and other accommodations for bicycling are also incorporated.

In addition, it is important to understand from examples throughout the world that transport ridership is likely not the most important factor in determining the level of economic development to be generated; real estate market conditions and the "sense of place" generated by the build environment are more important to such success.

Related to these success factors are the plans, policies, and institutions that support the sustainable development. For example, local land use plans, policies, zoning ordinances, other capital improvement programs and financial and non-financial incentives (e.g., density bonuses, property tax holidays, streamlined development application processes, subsidized loan support etc.) can have far greater influence that the type of public transport investment being contemplated. Other the other hand, familiarity and experience of the sponsoring public transport agency regarding land use issues will be very important to determining the level of success of public transport projects regarding sustainable development outcomes.

Moreover, the basic design principles for sustainable development are largely the same, whether contemplating a BRT rail project. These principles include balancing design for transport needs (e.g., interconnections with other modes, anticipated patronage demand, etc.) with needs for design for access to surround neighborhoods and a design for permanence and a "sense of place." To this end, interesting features of the public realm such as public art, landscaping, good, attractive signage and ample sidewalk space are also important features of the built environment needed for sustainable development.

CONCLUSION

For the past several decades, increasing attention is being paid to the role of good public transport in generating sustainable development in cities throughout the world. While this began with rail-based modes, policy makers in developed countries are now learning the lessons of their counterparts in developing nations that BRT can also help achieve sustainable development outcomes. To this end, policy makers must not overlook important lessons of urban design and design policy, regardless of the mode of public transport investment they contemplate.

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Measuring the Value of Multimodal Investments

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Introduction

With the completion of the Utah Transit Authority's (UTA) FrontLines program in 2013, five new rail lines expand rail transit service to West Valley, South Jordan, Provo, Draper, and the Salt Lake City airport.

The FrontLines program is the result of ballot initiatives in Salt Lake and Utah Counties. In 2006, Proposition 3 was passed by 64 percent of voters in Salt Lake County. This raised the local-option sales tax for regionally significant transportation projects. Passed at that time by 69 percent of Utah County voters was the "Utah County's Opinion Question" which was designed to increase transit funding in Utah County specifically for commuter rail. The transit projects included in the FrontLines program that were funded in part by the new tax are:

- Mid-Jordan TRAX
- West Valley TRAX
- FrontRunner South
- Airport TRAX
- Draper TRAX extension

In 2012, UTA's planning division hired InterPlan to quantify the effects of the FrontLines program investment by analyzing conditions in 2015 both with the five rail lines in place and without any of the new lines in place. The key objectives of this analysis were to compare "opening day" conditions (2015 build) to a transportation network that did not include the new rail lines and estimated what conditions would have been absent the referendum (2015 no-build) and, to a lesser extent, to pre-implementation conditions (2009). Additionally, in order to get a better sense of rail transit's impacts over time, InterPlan also looked at conditions in 2020, allowing for the incorporation of land use changes that result from rail infrastructure investment and related development.

Three of the five lines (West Valley TRAX, Mid-Jordan TRAX, and FrontRunner South) were open at the time this paper was prepared. The Airport TRAX opened in April 2013 and Draper TRAX opened in August 2013. This analysis does not consider the impacts of these transit projects incrementally, but rather views them as a completed network in 2015 when steady ridership is expected to be achieved. This analysis not only confirms and updates ridership numbers on each rail line but also offers guidance on ways to view the expectations and eventual results of large transit capital investments. To this end, three broad conclusions have emerged from this analysis of the FrontLines program.

1. The benefits of transit investments extend well beyond transit riders. The FrontLines program benefits highway users by taking cars off major roads that would otherwise add to congestion problems.
2. A multi-modal approach to transportation problems yields significant success. By having the vision to look at problems such as congestion on I-15 in Salt Lake County from a multi-modal perspective, improvements to both the freeway and the transit system have together solved or greatly mitigated one of the largest transportation problems in Utah.
3. The whole is greater than the sum of the parts. Each additional transit line offers new choices and opportunities for users and new transit infrastructure in one location may offer advantages that are far removed.

This report offers a summary of the benefits to the entire transportation network as a result of the transit investment made by UTA, specifically from the FrontLines program, and gives a quantitative assessment of both the transit and highway benefits realized because of this investment. It provides a review the basic assumptions of the analysis specifically with respect to the regional travel model, and quantification of the FrontLines program from a regional, "travel shed", and local perspective.

Assumptions

The regional travel demand model was the primary tool used in the analysis of the five transit lines. The regional model provides an overall look at the transportation network based on land use and socioeconomic data that is consistent with growth projections for the area. It offers quantitative information related to transit ridership and vehicle trips and allows for a consistent comparison of network conditions across a range of scenarios, in this case a comparison of 2015 conditions with the five new rail lines and without. InterPlan calibrated the regional model to existing conditions by comparing existing transit ridership numbers to model output. This step ensures the most accurate results, provides confidence in findings, and offers insight to the accuracy of the travel demand model. The results achieved in this step verified that even though the geographic scope of the regional model is large, it is an accurate tool for multi-modal transportation network analysis and a good resource for the examination of the five rail lines program.

The travel demand model used for the analysis of the five rail lines is the same regional model used to forecast ridership for each rail line in their respective environmental documents. While the model is the same as used in previous studies, the Wasatch Front Regional Council (WFRC) and the Mountainland Association of Governments (MAG) released an updated model version in 2011 that was used in the analysis of the five rail lines. This updated model, Version 7.0, was calibrated to more recent (2008/2009) transit ridership data for the region to better reflect existing transit ridership in its results.

The travel modeling for this analysis required making assumptions of the overall transportation network and what other planned or programmed projects would be built at the time of the opening of the five rail lines. The analysis was set up to compare conditions on the first day that all five rail lines are running with consistent ridership. Slight modifications were made to the regional model in order to most accurately reflect future conditions under a build and no-build scenario.

Transit Modeling Assumptions

Minor changes to the default WFRC 2015 transit network were made to make it more consistent with existing and planned service based upon input from UTA. These changes included refinement of the transit operating plans for each of the new lines as well as updates based on latest information. These updates mainly consist of removing future planned stops and transit service that is not likely to be in revenue operation by 2015 such as the 5600 West Bus Rapid Transit. It should be noted that UTA's original projected start date for all five rail lines in the Frontlines program was estimated to be the year 2015. Despite the recession, UTA's construction is ahead of schedule. Possible operating changes between 2013 and 2015 are being explored by UTA but are not included in this analysis.

Additional work was done to develop a 2015 no-build transit network that does not include the five rail corridors. Historically sales tax revenue has grown by approximately five percent per year. However, the economic recession that both the nation and Utah have been experiencing since roughly 2008 has negatively impacted UTA revenue. Because a large part of UTA's operations funding comes from sales tax revenue and because sales tax revenue dropped sharply and has yet to fully recover, UTA has undergone several revisions in service in order to remain within operating budgets. Due to this decrease in revenue, UTA staff recommended that modeled transit service should only increase by two to three percent per year. Specific changes suggested by UTA to the no-build transit network resulted in an annual sales tax revenue growth of 2.7 percent through the year 2015. Although the operating assumptions for the build network are well known and can be accurately modeled, the estimated operating assumptions for the no-build network may be overstated because of the sales tax revenue assumptions, thereby understating the benefits of the five rails investment in this analysis.

This growth in service assumed in the no-build scenario was apportioned roughly equal to the population growth of each county. The new service was geographically distributed using the WFRC 2015 transit network as a guide to where new service is planned within each of these counties. Transit service within Davis and Weber Counties was assumed to be the same between the transit scenarios since no FrontLines projects are located in these counties.

Highway Modeling Assumptions
The highway network assumed the projects and phasing of the 2040 Regional Transportation Plans of both the Wasatch Front Regional Council (WFRC) and the Mountainland Association of Governments (MAG), the respective Metropolitan Planning Organizations in each area. Most of the highway projects assumed in 2015 have been committed for funding in the Statewide Transportation Improvement Program while the 2020 highway projects were assumed from transportation plans where funding is only estimated.

Socioeconomic Data Assumptions
Population and employment were assumed consistent with travel model data for 2015 and 2020. This information is developed by WFRC and MAG for specific model years. Although it can be argued that the FrontLines program will result in changes to land use patterns, specifically with more intense (higher density and mixed-use) land development near transit stations, the analysis kept land use constant between the build and no-build assumptions. However, socioeconomic variables such as vehicle ownership, which is a function of transit accessibility, did vary between scenarios.

Results: Regional
There are many ways to discuss transportation parameters. To best understand the full impact of the five rail lines, this discussion focuses on both new transit ridership (those riders that start using transit because of the new infrastructure) and mode split. Mode split (or mode share) is a way of looking at the overall traveling public and understanding how they make their trip, whether by car, by transit, or by walking and biking. Additionally, this analysis distinguishes between the various types of transit such as commuter rail, TRAX, bus, express bus, and BRT. By going to this fine grain of detail, the specific impacts of the five rail lines are seen more clearly.

Transit Ridership
Regionally, the five new transit lines are expected to carry more than 30,000 new rail riders in 2015 over and above the rail ridership in 2009. Since some of the increased ridership is due to population growth and some is due to moving riders from bus and express bus to rail, the impact of the five rail corridors amounts

Line-by-Line Ridership Estimates of FrontLines 2015

	Total 2015 Ridership	Increase from Frontlines 2015 Program*
Blue Line (Sandy + Draper)	25,000	2,500
Red Line (Mid-Jordan + U of U)	26,000	3,400
Green Line (West Valley + Airport)	15,000	15,000
Frontrunner (Ogden + Provo)	15,000	9,600
Total	81,000	30,500

** Increase reflects total of new stations and lines and does not consider redistribution of riders* to nearly 20,000 additional transit trips in 2015 and about 27,000 in 2020 over what would have been without the five rail lines.

Ridership is affected even in areas that do not gain transit infrastructure through the FrontLines program. Davis County to Utah County total transit ridership increased nearly 800 daily trips on FrontRunner with its with service between Ogden and Provo. Both Hill Air Force and Weber State University also benefit from extending FrontRunner south of Salt Lake City into southern parts of Salt Lake County and down to Provo.

Vehicle Miles Traveled

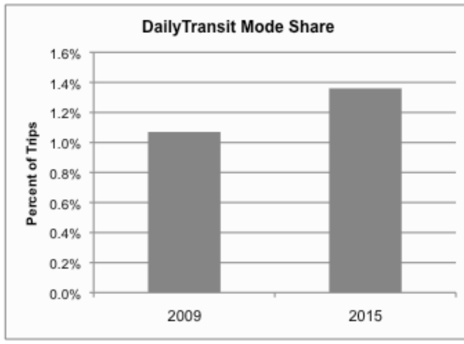
People that do not ride transit will benefit from the reduced traffic on various roads. Reduction in vehicles miles of travel (VMT), the total miles travelled by cars on the road network, is significant between the 2015 build and no-build scenarios. Regionally, miles traveled are reduced by 333,000 miles due to FrontLines projects. By comparison, this reduction is greater than the total 2011 VMT on many of the most congested roads in the Wasatch Front including Riverdale Road (103,246 VMT), 800 North in Orem (97,615 VMT), and 500 South and 600 South combined in Salt Lake City from I-15 to State Street (60,868 VMT).

In Salt Lake County, VMT is reduced by 213,000 miles on a daily basis due to the opening of the rail lines. As expected, Salt Lake County shows the greatest traffic reduction, followed by Utah County with a 77,000 daily vehicle mile reduction. However, the fact that travel is reduced in Davis County by 37,000 miles demonstrates how far-reaching the influence of the five transit lines is. Again, there is no new rail infrastructure in Davis County and residents there have not contributed to the funding of this transit infrastructure, yet they benefit from it in the form of less delay on their road network.

To put the Salt Lake County 213,000 mile reduction into perspective, it is slightly less than the total traffic increase resulting from the Salt Lake County I-15 widening, where traffic increased by 246,000 vehicle miles from before the project in 1996 to after the project in 2002. In fact, the traffic reduction in Salt Lake County due to the five rail projects is significantly greater than the traffic increase resulting from the Weber County I-15 widening, where traffic increased by over 67,000 vehicle miles from before the project in 2005 to after the project in 2009.

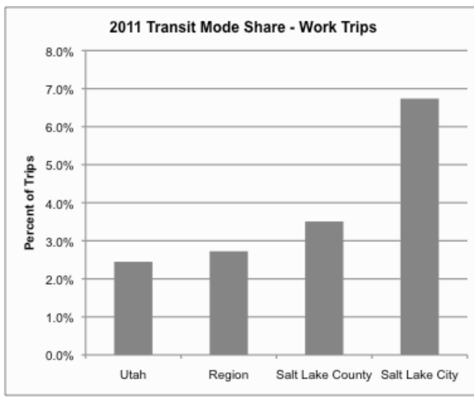
Hours of Delay

Hours of delay, or the total time that vehicles spend on the road due to congestion, is nearly 5,000 hours less under the 2015 build scenario, further demonstrating the benefit of transit investment to highways and drivers.



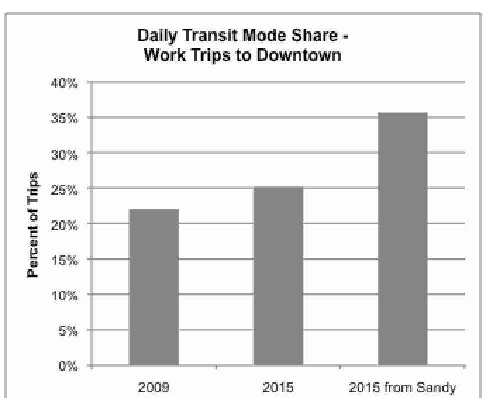
Mode Split

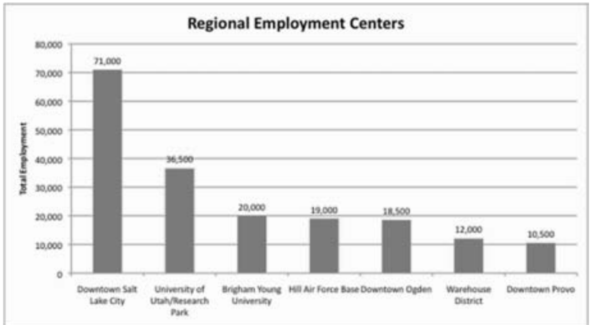
Regional-level mode split information shows a low transit mode share of all daily trips, roughly one percent of all trips in 2009 and nearly 1.4 percent in 2015.



When looking at the regional transit mode share for more specific groups, whether by trip type or destination, transit trips become a much more important part of the overall transportation picture. The 2011 American Community Survey (ACS) one-year estimates show that the transit mode share for work trips within Utah is the two times greater than the mode share for all trips, Salt Lake County work trips are three times greater, and Salt Lake City work trips are nearly seven times greater.

The Wasatch Front region has a strong commute pattern towards downtown Salt Lake City in the morning and away from it in the afternoon. The Central Business District in Salt Lake City accounts for 10 percent of all workers in Salt Lake County. It is the single largest destination for work trips throughout the Salt Lake Valley and therefore the mode split of work trips to this area is an important part of regional transportation conditions.





In 2009, about 22 percent of all work trips to downtown were taken on transit. Transit work trips increase to 25 percent in 2015 with the five new rail lines. Parsing the data even more shows that work trips from Sandy to downtown in 2015 are expected to be about 35 percent, more than 1/3 of all work trips from Sandy to downtown. These transit trips, attributed to both the FrontLines program and the original north-south TRAX line, and considering a vehicle occupancy of approximately 1.2 on I-15 in the peak hours, account for roughly three full travel lanes (for both directions of travel) on I-15.

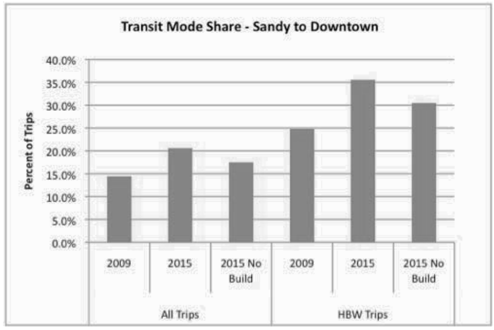
Looking at the ridership and mode split information at this level of detail shows how important UTA's transit investment is not only for transit riders, but also for non-transit users in offering significant reductions in the number of vehicles in specific corridors.

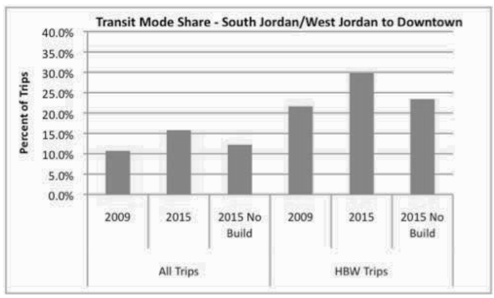
Results: Travel Sheds

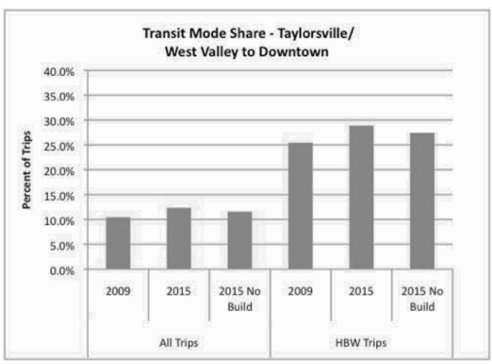
In order to better evaluate the FrontLines five rail lines and to understand their impacts at a smaller geography, results were examined via different "travel sheds" or transit markets. Travel sheds can be any origin-destination pair and any trip purpose. Example travel sheds might be work trips from Sandy to downtown, work trips from Davis County to Utah County, etc. Doing this offers a more accurate assessment of the impact of new transit infrastructure in a defined area and a better demonstration of benefits of the transit infrastructure to the highway network by quantifying vehicle reductions on specific roads. The travel sheds that were defined as a part of this analysis include:

- Sandy to Downtown
- West Jordan/South Jordan to Downtown
- West Valley/Taylorsville to Downtown

These origin-destination pairs were chosen based on the new rail transit infrastructure service areas and the ability to show impacts to transit ridership and the highway network that services similar origin-destination pairs.







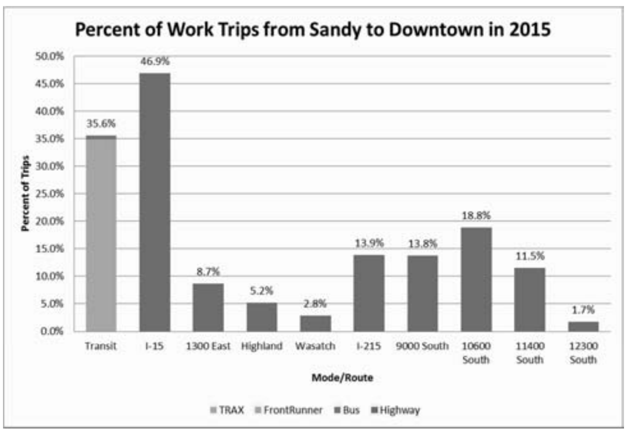
Mode Split

In the Sandy to downtown travel shed under the 2015 build scenario, over 20 percent of all trips and 35 percent of work trips (home-based work) occur on transit. This travel shed likely has one of the highest transit mode shares in the urban area having had the north/south TRAX line in place since 1999. As a comparison, work trips in 2015 under the no build scenario indicate just over a 30 percent transit share, again owing to the TRAX infrastructure that is already in place.

Similar trends are seen in the South Jordan/West Jordan to downtown market. Work trips in 2015 show a great discrepancy between the build and no-build networks, with transit share nearing 30 percent in the build scenario and about 23 percent in the no-build. Again, the proximity to the existing north-south TRAX line explains the relatively high transit share to begin with, and the expansion of the network to include the five new rail lines only capitalizes on that further.

Finally, transit mode share from West Valley/Taylorsville to downtown shows an increase in the transit mode share for work trips in the 2015 build scenario over the no-build, although to a lesser degree than the other two markets that were studied. This may reflect the fact that a major new north-south highway facility (Mountain View Corridor) is opening in the vicinity of this travel market by 2015.

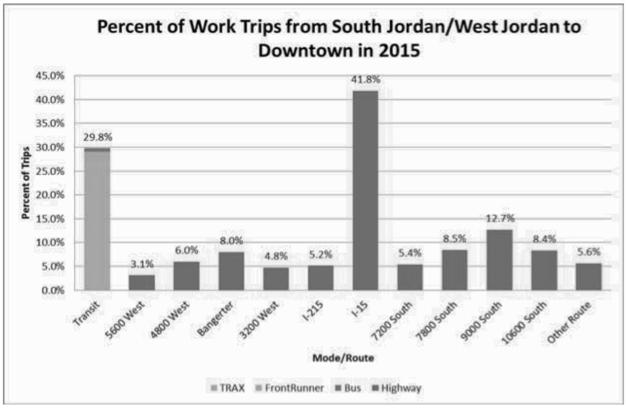
Trip Purpose
In addition to looking at transit mode share within these travel markets, it is also worth comparing mode share information with the share of trips that major roadways in each market accommodate. By looking at this information, the benefit of the five rail lines can be accounted for on specific roads within discrete markets. Assumptions incorporated in this information are based on trip comparisons for "home-based work trips" which are a travel model definition limited to those trips that either begin or end at home or work, not trips that include stopping at a school, daycare or grocery store between work and home. In addition, highway trips shown in the following information represent vehicle trips that occur on more than one road, so totals exceed 100 percent.



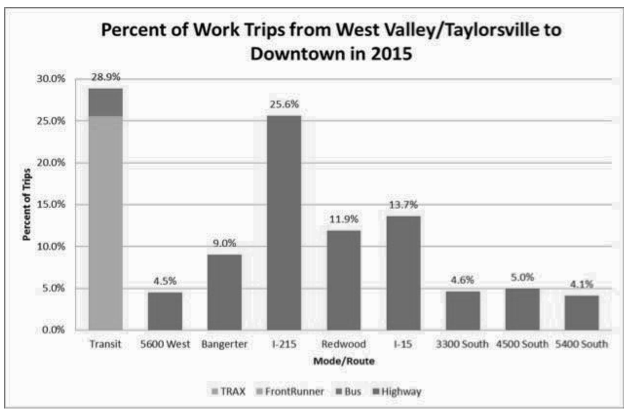
In the Sandy to downtown travel shed where transit mode share has been relatively high since the opening of the north-south TRAX line and remains high in future scenarios, TRAX accommodates 33 percent of the work trips out of a 35 percent transit mode share. In comparison, I-15 provides 47 percent of the work trips, but all other roads in the area well below the 33 percent share of TRAX, with I-215 being the other highest north-south facility with 14 percent of the trips. If these transit facilities did not exist, a facility (or the widening of existing facilities) roughly 2/3 the size of I-15 would be needed to accommodate these trips.

The Sandy to downtown travel shed demonstrates the success of a shared solution between highways and transit. Transportation planners in the late 1980s recognized that the growing traffic congestion on I-15 during the peak hours was only a symptom of the growing demand primarily of work trips between Sandy and downtown Salt Lake City. Planners embarked on a multi-modal study of I-15 and light rail (as well as other transit options), one of the first multi-modal corridor studies in the nation. Although Sandy and downtown Salt Lake will continue to grow and the transportation challenges are not over, this analysis demonstrates the role that transit plays in as part of a multi-modal solution offers a strong reminder that with multi-modal planning, transit allows highways to work better and more efficiently.

Information for the South Jordan/West Jordan to downtown market shows similar results to Sandy. I-15 still dominates work trips to downtown, yet transit accounts for 30 percent of work trips in this corridor. Again, without the transit infrastructure, the highway network would need to accommodate trips equivalent to 2/3 of the work trips that are carried on I-15.



Finally, the West Valley/ Taylorsville to downtown travel shed shows the most even comparison of transit work trips and vehicle work trips on a highway facility. Twenty-five percent of work trips in this market are taken on TRAX and an additional four percent on other transit. In comparison, I-215, the major north-south highway that serves this area carries 26 percent of the work trips to downtown and I-15 carries 14 percent. The transit network that serves this travel market accommodates more trips than the largest highway facility serving the same market.

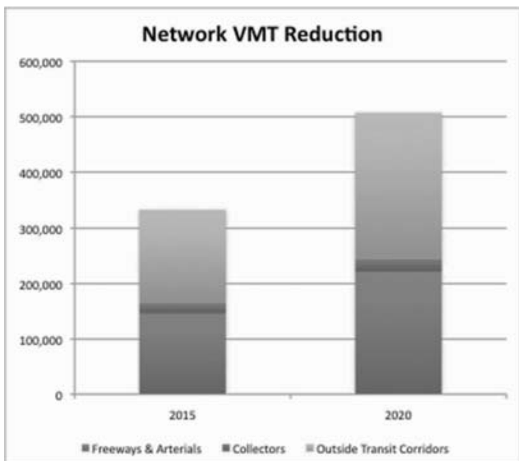


From this highway/transit comparison information, it may make sense to further the discussion of the influence of land use choices and development's impact on the highway system. From the evidence offered here, providing development that enhances transit use provides benefit to the highway system in addition to transit options and may initiate an important dialogue about land use and transportation choices.

Results: Transit Corridors

Finally, the benefits of UTA's FrontLines program can be seen from a local perspective by looking at the effect of the rail lines in the immediate vicinity of each individual transit corridor. Areas were defined by a buffer of roughly three miles around each of the four TRAX lines included in the five rails program. Within each of these buffers, detailed road network information was gathered from the travel demand model including change in VMT on specific roads.

In looking at the airport corridor under the 2015 build conditions, many roads with VMT decreases are seen along with several areas where VMT increases. Increases are mostly seen in downtown Salt Lake City and near transit stations. Decreases, however, are seen on major highway facilities within the corridor including I-80, I-215, and I-15.



The total daily reduction in VMT for roads in the airport corridor under the 2015 build scenario is 30,000 miles. Taking the analysis out an additional five years, the decrease in VMT is even greater with daily reductions over 45,000 miles. Again, the bulk of these reductions are on the major highway facilities within the defined corridor.

The West Valley TRAX line shows similar results, with reductions in traffic volumes on major facilities and some increases on lower functioning roads. Overall the traffic volume decreases outweigh the increases for a total reduction in VMT in the corridor of over 40,000 miles in 2015 and more than 70,000 miles in 2020.

In Draper, the local road network shows minimal areas of VMT increase. Total daily VMT reductions are similar to other corridors, amounting to over 30,000 miles in 2015 and nearly 55,000 in 2020.

Finally, the Mid-Jordan transit corridor shows the biggest VMT benefit to its surrounding road network, with the largest VMT decreases on I-15 and I-215. An aggregate of nearly 60,000 VMT are reduced from the surrounding network in 2015 due to new rail infrastructure and by 2020 the reduction equals over 70,000 miles.

Looking at the VMT reduction benefits of the overall transportation network, the number of miles reduced in 2015 exceeds 300,000 and in 2020, is more than 500,000. The majority of this reduction takes place on freeways and arterials and about half of it is within the boundaries of the four transit corridors defined above. The effect of traffic reduction from transit is slightly more profound in peak hours, when traffic congestion is greatest.

Conclusion

Transit infrastructure and service on the Wasatch Front took great steps forward with the implementation of the five rail lines included in UTA's FrontLines transit program. The benefit of the investment made by Salt Lake County and Utah County residents in 2006 in supporting an additional tax for transit projects can be demonstrated in a several ways. Specifically, regional travel demand modeling offers a quantitative assessment of conditions with (2015 build) and without (2015 no-build) the FrontLines transit program. This assessment focuses on three different perspectives by which to evaluate its impacts: from a regional basis, a "travel shed" or transit market perspective, and finally from a transit corridor, local view.

The FrontLines program, not surprisingly, clearly demonstrates increased transit ridership across the system and therefore provides benefits to transit users and potential transit users. More surprisingly, and arguably more importantly, the benefits of the five rail transit lines reach beyond transit users and beyond Salt Lake and Utah Counties. The highway network benefits greatly from this transit investment with demonstrated VMT and delay reductions in specific service areas and transit corridors. In addition, benefits to Davis County in both increased transit ridership and decreased VMT on I-15 in Davis County suggests that the positive impacts of UTA's investment are well beyond the specific locations of the investment and offer regional benefits.

Transit Oriented Development (TOD) in Edmonton, Canada

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ABSTRACT

Transit Oriented Development (TOD) is a walk able, mixed use (residential, commercial, employment, etc.) form of development focused around a transit station. In Edmonton City, the capital of Alberta, only 14% people use public transit. By the year 2040, Edmonton's population is expected to reach 1.15 million. To accommodate this growth, the City of Edmonton is pursuing more sustainable development options including TOD around existing and future LRT stations. In this paper an attempt has been made to evaluate the current development around 400 m of the existing LRT stations and determine the development principles for a successful TOD with respect to other successful city's TOD. However, not all the LRT stations are functioning as a TOD, but creation of a complete neighbourhood in which land uses are located accordingly to market fundamentals with proper integration of pedestrian, bicycle, auto, and transit network, can easily turn them into a successful TOD.

1. INTRODUCTION

Transit Oriented Development (TOD) is a walk able, mixed use (residential, commercial, employment, residential etc.) form of development focused around a transit station. Development should be within 400 m (walking distance) with an improve access of bicycle around the transit station. Concentrating higher density development near the station makes transit ridership and reduce the auto ridership. According to Parker et al 2002, "TOD is moderate to higher density development, located within an easy walk of major transit stop with a mix of residential, employment & shopping opportunities designed for pedestrians without excluding the car. TOD can be new construction or redevelopment of one or more building whose design and orientation facilitate transit use." Communities built in this way have proven to be particularly livable, sustainable and resilient places. Research shows that most of the trips during the peak periods are work trips and most of them are done by private car. TOD helps to develop job, employment facilities around the transit station which reduce the vehicle mile traveled (VMT) for work trips and hence reduce the auto trips. Because of these benefits, making communities more transit oriented is one of the key goals of transportation plans in Edmonton City.

Edmonton City, the capital of Alberta, having a population of 817498 (2012 municipal census) with an annual average growth of 12,000. About 60% of the trips are done by private cars which will take the city towards traffic congestion in near future. Only 14% people in Edmonton use public transit and another 4% walk or bike to work. Without augmentation of public transit ridership as well as modal shifting from private car to transit, sustainable development will not be possible. By the year 2040 Edmonton's population is expected to reach 1.15 million (The City of Edmonton, 2011). To accommodate this growth, the City of Edmonton is pursuing more sustainable development option including transit oriented development around existing and future LRT stations. In this paper an attempt has been made to evaluate the current development around 400 m of the existing LRT stations and determine the development principles for a successful TOD with respect to other successful city's TOD.

2. PRINCIPLES OF TRANSIT ORIENTED DEVELOPMENT

The main purpose of TOD is to decrease the private car ridership and increase the public transit ridership. Transit ridership can be increased if people can easily walk between many destinations at the beginning and end their trip. This can be achieved through providing increased densities, mixed land use (housing, employment, retail, commercial), pedestrian oriented design within easy walking distances from high quality transit. TOD aims to create healthier and more livable communities where people can live, work and shop. For a successful TOD, development should be done providing a mix of uses and densities that complement both transit users and local community, encourage transit use, managing safe circulation of pedestrians, cyclists, vehicles and parking. For achieving the goal of TOD, some certain should be ensured which are given below (City of Ottawa Planning, 2007; City of Austin, 2006; BART, 2003).

1. Land use: Ensure transit supportive land use (townhouse, apartments, childcare, hotels, medical clinics, restaurants, affordable housing, libraries, recreational and cultural facilities, fitness club, high school and post secondary institution) within a 400 metre walking distance of a transit stop or station. Discourage non transit supportive land use (low density residential development, generate high level of vehicular activity, create negative impacts for pedestrians, such as isolation, wide swept walks and numerous vehicle crossings on sidewalks) that are oriented primarily to the automobile and not the pedestrian, cyclist and transit user. Mixed land use pattern that support a vibrant area community and enable people to meet many of their daily needs locally, hence reducing the need to travel. Mixed land use includes variety of different housing types, employment, local services and amenities, retail shop school within a close proximity of one another.

2. Layout: Streets, laneways, pedestrian sidewalk and cycling connections will be made in a way to reduce distance to transit or any other destination. Locate building (apartment, office, retail shop, commercial) close to each other to encourage ease of walking between building and a public transit. This could be provided within one building or within several adjacent buildings. Ensure pedestrian safety and increase pedestrian accessibility. For example, create pedestrian and cycling "shortcuts" that lead directly to transit. Have to ensure "short cuts" are maintained and free of ice and snow in winter. Establish a good bicycle network around the station hub, station neighbourhood and station influence area.

3. Pedestrian and Cyclist : Ensure convenient, comfortable, safe, easily navigable, continuous, barrier free pedestrian connections that lead directly to transit station. For safe movement different material such as concrete for crosswalk or treatments such as painted patterns to provide visual identification of pedestrian routes for motorist. Ensure pedestrian connections are maintained and operational at all times when transit services are functioning even after building business hours. Provide weather protection (covered waiting area, heating, electricity) to make waiting for and getting to and from transit stops more comfortable. Ensure and increase bi-cycle facility by giving bike lane on right of way for bicycle along with provide convenient and attractive bicycle parking that is close to building entrances, protected from the weather, visible from the interior of the building and that doesn't impede the movement of pedestrians.

4. Parking : Transit oriented development doesn't means "no cars". Even with high transit utilization, many people will come and go by auto mobile. So huge parking facility is needed. Adequate parking lots in the station area should be provided for the car user, bicyclist. Locate parking lots behind the building entrance to ensure no hindrance of pedestrian and vehicular movement. Develop park and ride lots into mixed use transit or surface parking short distances away from the station.

5. Street Scope and Environment: Ensure quality benches, tree guards, street lighting, bicycle racks and garbage receptacles. Plant shade trees and shrubs to reduce urban heat and to create a more comfortable micro climate. Enclose air conditioner compressors, garbage and recycling containers and other similar equipment to make environment and air free from bad odor.

3. IMPACT OF TRANSIT ORIENTED DEVELOPMENT

According to Stiffler (2011), residents who lived in transit oriented development made fewer trips than auto oriented neighbourhoods. Analysis also showed that non TOD residents significantly used their auto mobile on a daily basis more than TOD residents. Research also shows that TOD residents choose transit for 13 percent work trips. Most of the work trips are done by car drive to work in a more time efficient manner than the time it took to wait for transit. Non TOD residents did not have any work trips by transit. According to Lund (2003), Gordon and Peers (1993), Handy (1992, 1996a, 1996b), Steiner (1996) and Shriver (1997) that housing near commercial development encourages greater pedestrian activity street layouts can effect residents willingness to walk or bike for localized trips. Cervero (1993) found that more than half the residents who moved within 1/2 mile of a Bay area Rapid Transit (BART) station switched travel modes from automobile to transit for community. Lund, Cevero and Willson (2004) found that residents living in TODs were five times more likely to use transit than the average worker in the same city. They also found that during 2003, employed working in offices located in TOD protected in TOD projects were 3.5 times more likely to use transit for travel to work than other workers. The proximity of TOD is an important factor that influences the likelihood of residents or workers to use transit or walk. Cevero (2006 a) found that transit ridership high within 1/2 mile of transit station in Los Angeles, Sacramento, San Diego, East Bay and South Bay (San Francisco). Vehicle miles traveled (VMT) depends on two characteristics mixed land use and access to transit. So successful TOD will ofcourse reduce VMT. Zhang and Yi (2006) developed a model and predicted that a transit system with TOD in Austin, Texas reduce the daily regional person miles traveled (PMT) and which will drop the congestion by 2.2 % in the year 2030. Handy and Clifton's (2001) study of walking behaviour in Austin, Texas neighbourhoods and Bagley and Mokhtarian's (2002) study of the San Francisco, California area, found that residents attitudes and life style choices had the most significant effect on travel demand where land use patterns have relatively little impact.

4. TRANSIT ORIENTED DEVELOPMENT WORLDWIDE

Transit Oriented Development is not a new or untested process. Lots of places around the world have or trying to build different government or private public ownership projects to develop transit oriented development. It is not a short term process rather than a long term process. Step by step development can convert a transit station to a TOD. Charlotte, Denver, Atlanta, Orlando, Adelaide, Vancouver, Kelowna, Calgary, Mont Saint- Hilaire trying to build TOD. Many countries around the world have developed transit oriented development. - Curitiba (Brazil), Guatemala City (Guatemala), San Francisco, CA Bay Area, Salt Lake City (UT Metro Area), Australia, Hong Kong, Paris (France), Hamilton etc. In USA lots of place are developed around a transit stations. Some successful TOD at USA are Dallas, San Francisco, Arlington County, Boston, New Jersey, Washington, Colorado, Portland. Most of the successful TOD have followed the certain criteria which are discussed earlier. Edward and Theodore tried to evaluate the potential site for TOD in Delaware. They consider certain criteria to weight the transit station and hence determine the lacking for a successful TOD. A brief study from their report is given below foe better understanding the evaluation criteria (O’Donnell and Patterson, 2010).

Case Study:

The Wilmington station at Delaware state, USA, is the 11th busiest station in USA, supporting 731,539 passengers in 2008 (Amtrak, 2008). The Wilmington station currently serves 90 trains each day (Wilmington Area Plan, 2008). Ticket office in the station is open in every weekdays and has wheelchair accessibility. Various commercial and institution are located within walking distance of the train station, including Bank, Law office, University etc. There are unique mix of business, residential, recreational and institutional land uses in the vicinity of the transit station. So this station has mixed use zoning district. The density of the North Easter station area has the highest density area in Delaware. Mixed land use helps to increase the access to food (grocery store, restaurant, farmer's market), open Space (parks, trails, baseball fields), entertainment (museums, malls, movie theatre, arts), health care (hospital, doctor’s office, pharmacy), education (school, university, libraries), housing (apartments, assisted living, houses), economy (jobs, businesses, industry, office space). There are lots of grocery around the station and in the residential area. Street trees, tree medians and sidewalk buffers that are incorporated into the environment leading to and at the transit station. Streets at Wilmington are in grid pattern. And the quality is high compared to suburban areas. This grid pattern streets increase the accessibility to station areas and surrounding neighbourhoods. Sidewalk for pedestrian are provided along Front street, to and from the station along roadways leading or adjacent to the train station. Bicycle pathways are available around 1/2 mile radius and increase the accessibility of the bicyclist. The city of Wilmington encourages alternative parking in all site design to alleviate excessive traffic congestion and parking shortage.

So mixed land use pattern, grid pattern street, high pedestrian and bicycle facility along with sustainable environment make the Wilmington a potential site for TOD. Foe evaluating TOD in Edmonton these case study can be followed. By considering the criteria which are used to evaluate the TOD of Wilmington, Edmonton's TOD can be evaluated.

5. EVALUATION OF TOD IN EDMONTON

The city of Edmonton defines transit oriented development (TOD) as urban development that is planned and integrated with a transit station and at its core. In a TOD, housing, shopping and employment are concentrated along a network within 400 meters of the transit station with easily accessible pedestrian and bicycle network. This paper mainly focus on the evaluation of TOD around the current LRT stations. Currently the transit have fifteen LRT stations covering total distance of 21 Km. City of Edmonton divided the stations into six categories. They are centre station, employment station, neighbourhood station, downtown station, institution/recreation station and enhanced neighbourhood station. From the analysis of different literatures and field inspection of 400 m of surrounding LRT stations, evaluation was made. For each category current characteristics and appropriate types of TOD for each station type was evaluated. Brief summary of the evaluation given below (The City of Edmonton, 2011).

1. Centre Station: Clareview and Southgate are categorize as this type of station. These stations are near large or regional shopping centres. Lots of retail shop and commercial activities occur around these stations.

- ***Current Characteristics** :* Its predominantly retail development next to major roadways, offering good regional auto access. Potential development site consist of mostly parking lots with other low intensity uses such as (small shop, money mar etc.). Streets are typically grid pattern with little or no pedestrian and bicycle access to and from residential areas. From the above characteristics it's clear that centre stations are not TOD. For developing TOD certain appropriate development, which are given below, is needed.

- ***Appropriate Types of TOD**:* Development of higher density residential area, ranging from duplex and row/townhomes to low, mid and high rise apartment buildings. Neighbourhood employment- professional offices and services close to the station must be established. Significant street oriented retail must be developed. Street should be in grid pattern in residential neighbourhood. Pedestrian and cyclist access to and from surrounding neighbourhood should be improved. For providing good environment to the residents new park and facilities must be ensured (The City of Edmonton, 2011).

2. Employment Station: Belvedere station is selected an employment station. City of Edmonton also selected this site as potential site for TOD. Within 2040 Belvedere will become a TOD site if the plan runs smoothly.

- ***Current Characteristics:*** Most of the land are undeveloped with low intensity employment such as warehousing and storage. Its adjacent to major roadways with good regional auto access. Streets are not grid within the development sites. Access of bicycle and pedestrians to existing residential areas are very poor or in some place absent. From the above characteristics it's clear that employment station is not TOD. For developing TOD, certain appropriate development which are given below, is needed.

- ***Appropriate Types of TOD:*** For increasing the job opportunity, low rise professional offices and services, such as corporate headquarters or research centers must be built. Must ensure medical campuses or hospitals and associated facilities and services. Higher density residential development, ranging from duplex and row/ townhomes to low, mid and high rise apartment buildings should be built. Street layout must be grid pattern throughout the development site. Must develop street oriented employment and neighbourhood serving retail. Major transit park and ride facilities should be ensured adjacent to major roadways (The City of Edmonton, 2011).

3. Enhanced Neighbourhood Stations: Coliseum, Stadium and Century Park are selected as enhanced neighbourhood station. These stations are near existing neighbourhoods.

- ***Current Characteristics:*** Most of the buildings are residential. Lack of mixed land use. Though there are some grid pattern street but they are not interconnected. Pedestrian and cyclist access throughout the neighbourhoods are not good. Park and ride available at Stadium Station. From the above characteristics it is clear that these development is not transit oriented. For developing as TOD, Certain appropriate development, which are given below, are needed.

- ***Appropriate Types of TOD:*** Have to build higher density residential apartment, ranging from duplexes and row/ townhomes to low, mid and high rise apartment building. Neighbourhood serving retail shops, restaurant, coffee shops, employment-professional offices and services close to station must be built to ensure mix development. Grid Streets have to be interconnected. Improvement of parking, pedestrian and cyclist access throughout the neighbourhood and to surrounding neighbourhood must be ensured (The City of Edmonton, 2011).

4. Neighbourhood Station: Mckernan-Belgravia station was selected as neighbourhood station. City of Edmonton select this station as a potential site for future TOD.

- Current Characteristics: Most of the buildings are apartment buildings and condominiums where most of them are single family homes with some multifamily housing. There are some retail stores, services and commercial/professional business, particularly in more mature neighbourhoods closer to downtown. Most of the residential area have grid streets. Some neighbourhoods have pedestrian and cyclist access direct to the station. So by considering the above characteristics it's clear that development need for creating a successful TOD around this station.

- Appropriate Types of TOD: Low to mid rise apartment buildings, duplexes or two story townhomes should be built along major roads on large sites. Neighbourhood serving retail shops, restaurants, coffee shops and small scale professional offices close the transit station must be developed. Improvement of pedestrians and cyclist access must be ensured for successful TOD (The City of Edmonton, 2011).

5. Institution/ Recreation Station: University, Health Science and South Campus Station are these type of Station. These stations are near education or medical campuses and facilities.

- Current Characteristics: Current Land use pattern is educational institution with some residential building. Medical and educational campuses have high transit ridership throughout the day. Recreational users also have high peak ridership during events. Streets are not grid pattern within the development sites. There are good pedestrian and bicycle access within campus boundaries but not in residential neighbourhood. These stations are not TOD. For successful TOD some certain development are needed which are given below.

- Appropriate Types of TOD: Neighbourhood serving retail shops, restaurant and coffee shops, small grocery and drug stores must be established. Professional offices and services close to the station must be built to create neighbourhood employment. Interconnected grid of streets, interspersed with neighbourhood parks must be ensured. Access of pedestrian and cyclist to surrounding neighbourhoods must be improved (The City of Edmonton, 2011).

6. Downtown Station: Churchill, Central, Bay Enterprise, Corona and Grandin stations are Downtown stations. These stations are in or immediately adjacent to Edmonton's downtown area.

- Current Characteristics: There is a wide mix of uses from high density housing, to employment, retail, education and recreation. Streets are in grid pattern with lots of parking facility. Easily accessible be pedestrians and cyclists. Environment within 400 m of transit stations are good. So these five stations are functioning as TOD.

Though apparently it looks like TOD. But the downtown area was developed before the station was built. So though these stations are functioning as TOD, but the development was not transit oriented.

6. FUTURE TOD IN EDMONTON

According to the 2011 statistics of Canada, by the year 2040 Edmonton's population is expected to reach 1.15 million, a significant increase from the current population of 812,201. To accommodate this growth, the City of Edmonton is pursuing more sustainable development options including transit oriented development (TOD) around existing and future LRT stations. For the successful completion of TOD City of Edmonton developed a guideline for Transit Oriented Development. A detail guideline for each and every criteria was covered by this guideline. According to the Edmonton's TOD guideline with in 2040 develop a transit based development with a mixed land use of residential commercial and employment around the 400 m of transit stations of Edmonton. Beside that, access of the pedestrians and bicyclist should improved in a way that the distance will be always least to the transit stations. TOD will help to reduce the private car ridership and increase the transit ridership. There are five projects are going on simultaneously which are given below. The five projects are:

- Mckernan/ Belgravia Station area Plan (The City of Edmonton, 2011)
- Millwoods Station area Plan (The City of Edmonton, 2009)
- Stadium Station
- Edmonton City Centre Airport Land Redevelopment (The City of Edmonton, 2012)
- Station Pointe (The City of Edmonton, 2003)

7. RECOMMENDATIONS

Most of the transit stations are not functioning as TODs. By providing a greater mix of uses near the transit station would improve the location functionality as TOD. The Downtown area, apparently development look like and support TOD but they were developed before LRT station. Development is not transit oriented. For making the TOD successful in Edmonton some development principles can be followed.

- Creation of a sustainable community requires a coordinated transportation and land use system. Develop a framework of mix land use within 400 m of each station. Focus higher density residential, retail and employment growth around LRT stations and transit centres to support city's investment in transportation infrastructure.
- Establish different mix land use around 400 m of current LRT stations to reflect the characteristics of surrounding areas and each stations role in the LRT network.
- Create a safe, direct, easily accessible and convenient circulation system for different types of modes, with an emphasis on pedestrians and bicycles.
- Make the environment sustainable, livable by developing parks, greenery, lakes and good management of waste disposal.

Lots of TOD projects are going on and one of their objective is to reduce the auto ridership and increase the transit ridership. Future research can be done to evaluate the impact of TOD in reducing auto ridership.

8. CONCLUSION

"Transit Oriented Development (TOD) is a term which encapsulates the process of focussing the development of housing, employment, activity sites and public services around existing or new railway stations served by frequent, high quality and efficient intra-urban rail services" (Cervero, 1998; Curtis et al., 2009). There is no doubt that TOD responds to fundamental real estate market principles and best practices for urban development. The city of Edmonton plans to support public transport as a means to decrease other public infrastructure investment. TOD can help to improve livability, shifting transportation modes, develop sustainable environment, transformation of urban form and diversify Edmonton's economy. Though not all the LRT stations are functioning as a TOD, but creation of a complete neighbourhood in which land uses are located accordingly to market fundamentals with proper integration of pedestrian, bicycle, auto and transit network can easily turn them to successful TOD. So key stakeholder should ponder over the matter and work together to develop a successful TOD not only in current LRT stations but also in future LRT station and transit centres.

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Investment Practices of Transit Service Providers in Land Development

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Abstract

In the United States, many transit companies depend on government subsidies to cover their operating costs. Subsidies that are currently given are not a sustainable solution, as transit agency deficits are likely to grow in the future due to increasing operating costs. One practice that has been successful in a few U.S. and international cases is encouraging transit agencies to invest in land development. The investments transit companies make can benefit them not only by increasing ridership when the development is designed to be transit-supportive but also provide extra revenue from the lease or sale of the developed land. This study, by means of a survey, identifies barriers to transit agency investment in land development and trends and opinions among different stakeholders that might affect a transit agency's decision to invest in land development.

Introduction

Transit has been recognized as an essential part of the American transportation network. Many Americans are unable to afford the high costs of owning and operating a car, while others choose not to drive for lifestyle or environmental reasons. Well-developed transit systems will not only serve those who do not drive but also encourage a travel mode shift from private automobiles to public transit. Such shift could reduce the amount of car trips an individual makes, and could have a positive impact on air quality. Furthermore, the creation of communities that are well-rounded with a mix of land uses and a built environment calculated to make daily life easy and pleasant without automobile use, will improve the overall quality of life of community members. In a recent inter-agency initiative in the U.S. of livability and sustainability communities, the key role of transit systems as a bridge between urban and transportation developments was reestablished (Office of Public Affairs, 2009).

Currently, many modes of transit exist in the United States. Rail and bus are the two predominant modes, with many areas having some variety of rail or bus system in place. According to the 2011 Public Transportation Fact Book, published by the American Public Transit Association, or APTA for short, transit trips in the U.S. numbered 10.4 billion in 2009, continuing a trend of increase in trips by public transportation. However, such service comes at a price: transit operating costs were $37.2 billion 2009 (APTA, 2011). Many U.S. transit agencies are in a state of financial dependence on government subsidies to cover their operating costs. The total amount of subsidies given to transit companies in 2000 was 22.8 billion dollars (Pucher, 2004). Subsidies from the lower levels of government covered 56% of the

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operating costs of US transit agencies in 2009, while only 37% of those operating costs were covered by revenues from fares (APTA, 2011).

In some areas of the world, transit agencies invest in land development and enjoy financial independence and stability. Practices that encourage transit agencies to develop land in a transit-friendly manner are expected to have a positive impact on transit ridership. As transit ridership increases, so would transit agency profit. Once the investments start to turn a profit, whether from leases or from increased farebox revenue, that profit could then be re-invested in future development, and the profits that amass would decrease the transit agency's dependence on subsidies. Additionally, when transit agencies develop land to be transit-friendly, typically more livable and sustainable communities result.

This research aims to investigate to what extent these investment practices are recognized in the U.S., and what the barriers are that prevent transit agencies from such investment and participation in land development. The first step in the research is to conduct a thorough literature review. The literature review attempts to address three questions: (1) What is the current state of transit in the United States? (2) What are some current practices involving transit companies in land development? (3) What factors affect transit company investment in land development? The study also includes a survey of expert opinion to identify the barriers and trends that influence the investment of transit agencies in land development.

Current Practices

Practices of Transit Agencies' Involvement in Land Development

With transit in the precarious state it is in today, the practice of transit companies participating and investing in land development is not widespread. However, the practice is not altogether non-existent.

Two of the more recognized forms of transit companies' participation in land development are transit-oriented development (TOD) and joint development (JD). Though many definitions exist, TOD essentially focuses on the development of land around an existing transit station or hub. Lai (2008) defines 'land around' as the areas, whether public or private, within walking distance of a station. The size, population density, and the mixture of land use can vary significantly from case to case depending on the size and location of the city in question. On the other hand, JDs are usually smaller in their scales (Cervero et al., 2002), often planned and implemented concurrently with proposed public transportation facilities (Beltran et al., 1986), and frequently built on public land, usually directly on top of transit stations (Lai, 2008). As of 2012, there were over 180 TODs and JDs in the U.S., according to articles and various internet sources[1].

The participation of transit service providers in land development can take several forms at several levels. Cervero et al. (2002) identifies three main levels: proactivism, coordination and facilitation, and inactivity. "Proactivism" involves transit agencies "aggressively seeking to influence land development around their transit facilities." This means that transit companies will proactively seek out

[1] Sources include Cervero et al (2004) and websites of various transit and government planning agencies.

opportunities to develop their own land around transit stations as well as actively attempt to influence the owners and developers of land they do not own to develop in such a manner as to promote transit usage. In these cases, the transit agency initiates and takes a leading or “driver” role in the development. The practice of interest to this study, that of transit agencies investing in land development, often comes from agencies active in the highest level of involvement. “Coordination and facilitation” is a more common level of involvement that transit service providers take in land development than is proactivism. Coordination and facilitation can include the transit agency consulting with developers about how local land can be developed to encourage transit usage and improve the communities around transit stations. Transit agencies performing a coordination and facilitation role may also involve in discussions on government transit incentives to cities where developments are constructed to fit with and promote transit. This level of involvement implies that the transit agency is not the driving force behind the development. However, as will be discussed in the next subsection, it is observed that coordinating and facilitating transit agencies sometimes would also invest in land development. Inactivity, on the other hand, is a complete lack of involvement and investment in land development. Transit agencies can only react to development plans, and have little influence over development. As a result, they derive very little profits or benefits from land development in their area.

Transit Investment in Land Development

Transit investment in land development is one practice that could help transit companies overcome their financial woes. The practice, which is common in some areas of the world, is not very common in the United States. This subsection will first describe several successful cases of transit agencies investing in land development, followed by a brief summary of lessons learned from these case studies. The next section will further investigate factors influencing transit agencies’ participation and investment in land development by means of a survey of expert opinions.

Successful cases of transit agencies investment in land development often involve transit agencies practicing in the most active level, proactivism, described in the previous subsection. Perhaps the best example of proactivism of transit companies in land development in America is the case of the Washington Metropolitan Area Transit Authority (WMATA). According to Cervero et al. (2004), WMATA “aggressively seeks out mutually advantageous transit joint development opportunities.” WMATA owns the land on which it pursues joint development, due to the federal government’s financial assistance before the metro system was even built in the 1970s. In acquiring the land to build the original metrorail system, the federal government bought more land than was strictly necessary to avoid creating unusable leftover land parcels, and the property became WMATA’s to develop later on (Cervero et al., 2004). With the land readily at their disposal, the company was able to partner with land developers to create developments that can be leased or sold to generate great revenue. Indeed, as of 2004, WMATA’s Metro Center in Bethesda generated the most profit of all the TODs and JDs in the U.S. with $1.6 million in lease profits (Cervero et al., 2004). Doubtlessly, ridership and revenue from fares went up as the development attracted new riders.

Internationally, perhaps the most successful case of transit agency investing in land development is that of the Mass Transit Railway Corporation (MTRC) in Hong Kong, China. 37% of the public transit trips in Hong Kong are made on the railways of the MTRC (Loo et al., 2010). The mechanism that the MTRC uses to involve itself in land development is the Rail+Property Development (R+P) system. First, the government of Hong Kong gives the MTRC a land grant, thereby saving the company the trouble of purchasing the land around the proposed rail stations. A developer must then purchase the rights to develop from the MTRC at a much higher after-rail price. The developer and the MTRC reach an agreement about co-ownership of the property, the way the property will be developed to meet the livability and sustainability goals of the community, and the way profits from the development will be divided (Cervero and Murakami, 2008). Since the government and the privately-owned MTRC partner to make these large TOD projects a reality, the projects themselves can also be considered as JDs. In fact, Agence Francaise de Development and the French Ministry of Ecology, Energy, Sustainable Development, and the Sea, or AFDFMEESDS, (2009) cites the Hong Kong developments as the most successful joint developments in the world. Of course, the biggest benefit resulting from the involvement of the MTRC in land development is profit to the MTRC. Cervero and Murakami (2008) shows that R+P projects had a substantial positive impact on housing price premiums, although the increase in ridership due to R+P developments was not statistically significant. Basically, the investment in R+P developments has been financially remunerative to the MTRC.

Investment in land development can also come from transit agencies that only participate in a “facilitation and coordination” role. One such example in U.S. is that of Plano, Texas. The Dallas Area Rapid Transit (DART) agency worked closely with the city of Plano to create a transit-friendly environment in downtown Plano, Texas. In this case the city was the driving force behind the development and urban rejuvenation, but a significant amount of the property that was developed was purchased from the previous owners by DART in the late 1990’s (Turner, 2012). DART took the role of facilitator and coordinator. Their purchase of the land and agreement to assist the development greatly aided the development process, but the actual development itself was set in motion by the city of Plano before DART became involved. The investment benefited DART in multiple ways. For example, the agency met its ridership goals for 2010 (Turner, 2012).

One international case of facilitating and coordinating transit agencies investing in land development is that of Japan. In the case of the JR East and Tokyo Metro companies, a term of their privatization deal in the late 1980’s was the granting of land to the companies for development and real estate purposes. In this way, the subsidies that are given to transit companies in Japan are on a smaller scale than those given to agencies that do not participate in land development in other nations (Priemus and Konings, 2001). The subsidies may be small, but the benefits that the transit agencies reap from their investments in land development are big. Japanese rail companies made 5-42% of their operating income from land value capture activities such as real estate (AFDFMEESDS, 2009). Another unique international example is that of Copenhagen, Denmark. Metroselskabet, the public transportation company responsible for Copenhagen’s public transit system, derived from its participation in land development. According to AFDFMEESDS (2009), the company paid for half of the cost of developing a line addition to the transit system by selling plots of land owned by the city of Copenhagen, which is a partial owner of the company, and other governmental agencies. The other half of the costs were covered by fares from ridership after the land was developed and sold. In the case of Copenhagen, the city was the driving force behind the development. In this case, transit agencies did experience direct benefit from their involvement in real estate and development by covering the costs of a new line.

The main lesson that can be learned from these case studies is that the level of involvement a transit agency takes in land development and investment can affect the profits received. The proactive agencies mentioned in this section derive massive amounts of profits from revenues from land sales, while the example of a coordinator and facilitator agency, DART, derives less benefit from the smaller-scale development. As with anything else, the level of involvement taken does in fact affect the profits received from investments in land development.

Preliminary Feasibility Analysis

Benefits of transit agencies participating and investing in land development are widely recognized, including both indirect benefits to the environment and the society and direct benefits to transit agencies themselves through profits from leases and land sales after development and increased ridership that the developments generate. However, using data on the total number of transit stations in the U.S. from the Center for Transit-Oriented Development National TOD Database and several articles and internet sources for data on the number of TODs and JDs in selected states[1], this study estimates that only 6% of existing and proposed transit stations areas are considered to be TODs or JDs. This estimate does not reflect, however, other facets of transit agencies' involvement and investment in land development. By means of a survey, this section investigates to what extent the practice is recognized and implemented in the U.S., and how stakeholder attitudes and other factors may affect the level of transit agencies' involvement and investment in land development.

Influencing Policies

There are many policies and practices on the regional, state, and local level throughout the U.S. that encourage the implementation of TODs and JDs and effectively encouraging transit agencies' participation and investment in land development. These policies include the provision of subsidies and financial aid, zoning policies, parking policies, and trip reduction ordinances.

The provision of subsidies and financial aid can affect a transit agency's decision to participate or invest in land development. Anderson and Forbes (2011) notes that the funding for TODs can be dedicated to three TOD stages: TOD planning, land purchase, and TOD construction. These funding initiatives may be given to transit agencies in some cases or to developer agencies in other cases. Regardless of which agency receives it, the availability of funding, can ease some of the financial burden and risk associated with a project. This could encourage transit agencies to invest in development, even if the subsidy or funding was not given to the transit agency itself.

Zoning policies refer to regulations and laws that restrict land use and density in an area. Zoning policies in many areas encourage the suburban ideal of low-density sprawl. If zoning policies could accommodate or even encourage mixed-use and high density development, at least around stations, they could encourage transit-friendly development in some areas (Cervero et al., 2002; Morris, 2002). Examples of transit-friendly zoning policies include Montgomery County in Maryland (Morris, 2002) and Phoenix, Arizona (Atkinson-Palombo and Kuby, 2011). The correct atmosphere of zoning policies could make involvement in land development easier for transit companies, as the companies can develop the land to encourage the use of their service without going through the added trouble of changing existing transit un-supportive zoning policies.

Parking policies are identified as another influencing factor on transit agencies' involvement and investment in land development. Banister (2005) notes that parking policies influence modal choice in the short term and location choice for development in the long term. Unlike U.S. policies that set minimum numbers of parking spaces, Canadian and European regulations set maximum numbers instead (Pucher, 2004). If parking is free and plenteous, many will choose to drive to their destinations, and public transportation will likely suffer, even when transit companies take the initiative to get involved and invest in transit-friendly development.

Trip reduction ordinances are also considered as one possible influencing policy since they encourage citizens to use transit (Hendricks and Goodwill, 2002). People who intend to use transit to meet trip reduction ordinances will be able to do so more effectively if they live or work in a transit-friendly development. In this way, trip reduction ordinances generate demand for transit-supportive development. This demand could encourage transit agencies to invest in land development, as higher demand spells higher lease profits.

Survey of Expert Opinions

To examine the opinions of experts regarding the feasibility of transit agencies' investment in land development, this study conducts an internet-based survey. One goal of the survey is to reveal the general attitudes of American transit officials, land developers, and government officials towards this practice. The survey also aims to understand the factors that affect the involvement of transit service providers in land development and to verify literature review findings by comparing current involvement levels against existing policies.

The interview questions were designed to target 6 groups of issues, including subsidies, other existing policies, current levels of involvement in land development, potential for new developments, information about the state of transit in each area, and opinions of agency representatives regarding the practice of transit investing in land development. Interviewees were selected and contacted based on their affiliation with transit companies, land development companies, or state Departments of Transportation. A general invitation was also sent out to members of the Public Transportation Committee of the American Society of Civil Engineers, Transportation and Development Institute.

In total, 17 people responded to the online survey. Among those 17 respondents, 8 were transit agency representatives, 2 were land developers, and 7 were government planning agency representatives. Due to the low response rate, land developer survey responses were not included in the analysis. While the small sample size does not allow researchers to draw rigorous statistical results, it does identify some trends in the data that will be discussed later. The responses reflected agencies from various locations and with varying populations. Of the agencies that responded to the survey, 7.1% are from the Northeast U.S., 14.3% are from the Central U.S., 57.1% are from the Southeast U.S., and 21.4% are from the Southwest U.S. The majority of the areas surveyed (40%) represented populations of either 250,000 to 500,000 or 1 million to 2 million people. Three population groups, areas of less than 100,000 people, 100,000 to 250,000 people, and 4 million or more people, accounted for 13.3% of the total respondents each. The least represented population groups are the 750,000 to 1 million people, 2 million to 3 million people, and 3 million to 4 million people groups at 6.7% each.

None of the surveyed transit agency currently participates in land development at a proactive level. A majority (53.3%) of the agencies acts as facilitators or coordinators, 33.3% are inactive in land development, and the remaining 13.3% were unable to answer the question.

The survey identifies four barriers that prevent transit agencies from actively participating and investing in land development. Some of the barriers identified, such as parking policies, confirm the findings of the literature review. The survey also reveals one barrier that has received less attention in the literature, namely transit agencies' perception of the benefits of their involvement in land development. Additionally, two major findings regarding various agencies' attitudes toward transit agencies investing in land development are discovered by the survey. The results of these analyses are presented in Table 1.

Table 1. Identified Barriers and Trends of Transit Agencies' Investment in Land Development

	Barriers
1	Presence of free parking
2	Lack of initial funding
3	Lack of land development expertise within transit agency
4	Lack of recognition of connection between involvement and benefits
	Attitudes
5	Knowledge about the practice is limited
6	Government planning agency representatives are highly supportive of the practice

The four barriers include presence of parking, lack of recognition of the benefits, lack of land development expertise, and lack of initial funding. The first two barriers are identified by cross-tabulating transit agencies' current involvement levels with existing policies and their perceptions of benefits. The latter two are identified from survey questions directly addressing factors that may change transit agencies' decisions to participate and invest in land development.

For parking, the presence of free parking corresponds to a 26.7% decrease in transit agencies participating in land development at the coordination and facilitation level. An increase of 60% in transit agencies that are inactive in land development is observed with the presence of paid parking.

The lack of recognition of the benefits that could result from transit agencies' participation and investment in land development is also a barrier. Of those agencies that participate at the coordination and facilitation level, 66.7% recognized increased transit ridership as an important community benefit, and the remaining 33.3% recognized increased economic activity as a benefit to society. All of the transit agencies that recognize increased ridership as a benefit to society, a benefit that would also directly profit the transit agency itself, participate at the level of coordination and facilitation. Of the agencies that are inactive in land development, 50% recognize reduced congestion as a benefit to the community, and 50% recognize increased economic activity as a benefit. Of the agencies that recognize increased economic activity as a benefit, only 66.7% participated at the coordination and facilitation level, while 33.3% participated at the level of inactivity. Of the agencies that recognize reduced congestion (a benefit that does not directly benefit transit agencies) as a benefit to society, 100% are inactive in land development. Note that not a single inactive agency considered increased ridership as a significant result of transit involvement in land development. This result reveals that a transit agency is more likely to participate in land development more actively if it perceives direct benefits to itself.

A lack of land development expertise within the transit agency itself was identified as a barrier to involvement in land development by 75% of the responding transit agencies.

The lack of initial funding as a barrier makes sense as well, as 80% of the transit agencies surveyed claim that the provision of grants or subsidies for TOD activities such as land purchase would affect their decision to invest in land development, while 100% of the transit agencies surveyed feel that grants for the planning and construction of new developments would affect their decision to invest in land development.

The survey also revealed a weak but unusual trend. Data from the study shows a lack of trip reduction ordinances corresponding to higher percentages of agencies participating at the coordination and facilitation level, but not necessarily the proactivism level of involvement (since none of the agency surveyed currently participate at that level). While only 50% of agencies subject to trip reduction oridnates (1 out of 2) participate in land development as a coordinator and facilitator, 70% (7 out of 10) function at the same capacity from arears that are not subject to trip reduction ordinates. It should be noted that the trend might not be statistically significant due to the small sample size of agencies that are subject to trip reduction ordinates. Nonethelss, this trend provides an interesting insight on trip reduction policies. They might be a double-sided sword—it is possible that the ridership resulting from trip reduction ordinances leads to enough farebox revenue to make participation and investment in land development less appealing. Also, the study is not able to draw a clear conclusion on zoning policies. Because these these trends among the data are weak, they are not presented in Table 1.

The attitudes identified in Table 1 reflect the opinions of transit and government planning agency representatives regarding the practice of transit investment in land development. A lack of awareness of the practice is very common, as half of the transit agencies and a third of the government agencies surveyed had not heard of the practice before taking the survey. However, the survey results do indicate that government planning agency representatives believe transit agencies should invest in land development.

Conclusion

This study conducted a literature review on policies, practices, and case studies relevant to the practice of transit investment in land development and conducted a survey to confirm barriers and trends relating to the practice. The results of the literature review indicate that transit investment in land development is successful in many cases. However, there are barriers to transit participation and investment in land development. The survey results in this study have confirmed some barriers recognized in the literature, such as the presence of free parking, a lack of initial funding, a lack of the recognition of the benefits of transit involvement in land development, and a lack of land development expertise within a transit agency. But the impacts of zoning policies and trip reduction ordinances cannot be clearly identified. It is possible that this is due to the limited sample data. But some of the policies, such as trip reduction ordinances, could actually have both negative and positive impacts on transit agencies' active involvement in land development. Furthermore, trends of attitudes are identified that reflect the lack of awareness of the practice. However, strong government support for the practice exists among those officials who are aware of it. These barriers and trends can be used to help shape policies that will encourage transit investment in land development.

This study provides a starting point for future investigation into the highly profitable practice of transit agencies investing in land development. Future research might include repeating the statistical analyses for a larger data set, since this particular study only surveyed a relatively small number of professionals. Such a study could uncover trends that are of more statistical significance than what this study reveals. Finally, a quantitative feasibility study can be conducted to provide more insight into the practicality of the practice in the U.S.

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Innovative Concepts in First-Last Mile Connections to Public Transportation

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Abstract

Congestion within the world's transport systems continues to worsen despite rising fuel prices, harsh economic times, energy security issues, and evidence that transportation related greenhouse gasses (GHG) from the combustion of fossil fuels are contributing to the erosion of our natural environment. Despite these issues, vehicle miles traveled (VMT) of single occupant vehicles (SOV) continues to rise and transit ridership struggles.

Individuals demand a transport system that is both flexible and convenient. A majority of travelers prefer the automobile, providing door-to-door service, as the most reliable and convenient form of transport. This reality increases VMT and compounds congestion and related environmental impacts.

It is well known that a vibrant transit system such as a subway, commuter rail, or Bus Rapid Transit (BRT) line can provide an energy efficient, safe, and practical way of accomplishing necessary trips. However, beyond the core service area of a transit service, attractiveness and efficiency quickly diminish for the user. The ½ to 1-mile radius outside the core is referred to as the first-last mile. Individuals either choose not to walk to the system, or find it difficult, unsafe, or insufficient in meeting their needs and quickly turn to the auto for mobility.

In the United States, a dispersed pattern of land use is predominant outside urbanized regions. Schools, homes, industry, and retail districts are scattered and difficult to serve with anything other than an automobile. This trend is also growing internationally. The growth of the suburb-to-suburb commute complicates the use of fixed-route transit systems. Annual VMT grew steadily over the last four decades, and only recently declined as a result of a slowing economy.

There are a host of policies and strategies being developed or deployed to meet the first-last mile challenge. Operational strategies and technologies are being developed or enhanced to meet the mobility needs of a growing population, anticipating demand for cleaner, cheaper, and more flexible options to combat growing congestion and environmental concerns.

Introduction

Transit is most effective for trips of moderate to long distance on busy corridors. Walking and bicycling, on the other hand, are effective choices for trips of shorter distance. The combination of walking and bicycling to transit can provide a high level of mobility in terms of overall travel time. However, this combination is not always possible. For many, transit use is inconvenient since station endpoints may be located beyond their comfortable walking or biking distance. This leads to the use of the most convenient form of mobility for door-to-door trips --the private vehicle. This scenario is known as the first-last mile dilemma of public transport. It is the inability to adequately compete with the private vehicle, which leads to low ridership in public transportation.

The success of public transportation, therefore, can often be limited by poor "first -last mile" access to the system. For instance, the lack of safe walking and bicycling access can be barriers to public transport utilization. Without adequate sidewalks, pathways, or roadway crossings in the area around nodes, access to transit can be dangerous, unfriendly, boring, or inefficient. It is essential to develop pedestrian and bicycle infrastructure if potential users of transit are to have safe, convenient, and practical access routes to existing systems. Providing amenities for bicycles and cyclists at transit stops or stations can be less expensive than merely providing parking for automobiles. Providing safe access allows bicyclists the opportunity to make longer trips. Whereas distance can prevent a bicycle trip or commute, public transportation can provide a link to previously inaccessible destinations. This relationship provides an environment which reduces SOV use and can ultimately reduce VMT.

Amenities such as benches, shelters, and lighting at stops and stations are also essential for pedestrian comfort and safety. The most successful and useful public transport systems have safe and convenient access points and provide comfortable waiting areas. In the most successful instances, stations include aspects of transit-oriented development (TOD) such as retail and entertainment options, which encourage and support greater use of public transportation and entice pedestrians to utilize areas around transit nodes.

When the most basic solutions such as walking or biking to transit are not feasible, other mobility options can be employed to solve the first-last mile dilemma. These alternatives can help close the gap for travelers whose origin or destination cannot be conveniently reached from the nearest transit stop/station by walking or biking due to distance, terrain, street patterns, or real or perceived safety issues. This paper will review current and possible future mobility solutions, as well strategies that are being revisited in the light of new technology and demand.

These mobility options range in complexity, adding to the fluid enhancement of the overall mobility of travelers and to the effectiveness and utilization of existing transportation networks. Options include the planning and incorporation of enhanced pedestrian and bicycle access, such as the implementation of bikesharing systems, the use of new carpooling strategies, the development of traveler information systems, new forms of jitneys and other creative operational techniques.

Current Mobility Solutions

Bike Sharing

Bike sharing is a form of short-term bicycle rental where people have access to a shared fleet of bikes on an as needed basis. These systems provide convenient access to bicycles for short trips, such as running errands or transit-work trips, so that users need not worry about using their own bike or transit access issues. Internationally, cities of all sizes have begun experimenting with bicycle sharing programs. Until recently, bicycle sharing programs have experienced low to moderate success, but innovations in technology in the last five years have given rise to a new generation of technology-driven bicycle sharing programs. These new programs can dramatically increase the visibility of cycling and lower barriers to use by requiring only that the user have the ability to bicycle and some form of electronic payment (smart card, credit card, or cell phone).

45 years ago, bikesharing emerged in Europe as a transportation mode. Since its inception, bikesharing systems have evolved to address geographic and technological demands. Bikesharing has expanded to include four continents undergoing three evolutionary stages, including: 1) First generation white bikes (or free bike systems), beginning in Amsterdam in 1965; 2) Second generation coin-deposit systems, which started in Copenhagen, Denmark in 1995; and 3) Third generation IT-based systems.

Emerging fourth-generation systems include all the main components seen in third generation systems but differ in that they are linked with public transit. The goal is seamless integration of bikesharing with public transportation and other alternative modes, such as taxis and carsharing. This means that bikesharing stations and parking are conveniently located near transit stations, transportation schedules are coordinated, and a single payment smartcard creates access to all available options. These systems are growing worldwide. As of 2011 an estimated 136 bikesharing programs existed in 165 cities around the world. These systems continue to demonstrate the potential to reduce GHGs and fuel consumption by discouraging personal vehicle use for daily mobility. (Shaheen, 2011).

B-Cycle, the bikesharing system in Denver, CO, revealed that according to a survey of its members, 43.16% of B-cycle trips replaced car trips, resulting in the reduction of approximately 300,000 pounds of carbon emissions and displacing the use of approximately 15,868 gallons of gasoline. (B-Cycle, 2012). However, the future demand and long-term sustainability of these systems is uncertain. Existing obstacles include limited and supportive infrastructure (i.e., docking stations, bike lanes), theft, high technology costs, funding considerations, and safety issues. More in-depth understanding and research on bikesharing is needed. This includes bikesharing's social and environmental benefits, the conditions in which it thrives (e.g., cities in which biking is less popular as a daily mode and residential/business storage is limited), business models, operational understanding, advanced technology applications, and the potential role of public policy in maintaining this mode and supporting its expansion.

Flexible or "Casual" Carpooling

Flexible carpooling, also known as "slugging" or casual carpooling, can complement existing modes of public transport. Casual carpooling refers to the sharing of a ride with a driver and one or more passengers, where the ridesharing between the individuals is not established or prearranged well in advance but coordinated shortly before the trip. Rides are shared to and from popular origins and destination points, such as from residential neighborhoods with nearby bus stops to downtown business districts. Casual carpooling provides an alternative to traditional ride-matching and formal carpool/vanpool programs. It differs from traditional carpools in that it is designed to provide an instant "real-time" match of potential drivers and passengers traveling to and from the same area. The advantage of flexible carpooling over regular "fixed-schedule" carpooling is that the participants do not have to meet at a fixed time. Carpool drivers or passengers can leave home or work at any time and still form their carpools "on the fly" at designated areas generally located near transit stops.

In contrast to formalized carpooling programs, casual carpooling maximizes travel flexibility and better accommodates occasional and/or unscheduled need to share a ride. Casual carpooling also differs from formal carpooling and the commonplace sharing of rides among friends and family members in that drivers and passengers typically don't know each other in advance and may never travel together again. Casual carpooling requires minimal advance planning and accommodates variable travel times, reducing the participation barriers to traditional carpooling. In 2009, almost 14 million Americans carpooled and represented 10 percent of work trips nationally – more than all other non-SOV work travel modes combined. Carpooling also serves other trip purposes, such as school, recreation, and shopping. This is important because 71 percent of VMT occurs for non-work trips, accounting for most of transportation's GHG emissions, energy consumption, and household transportation costs. (Oliphant, 2011).

Folding Bikes

Foldable bikes expand the"bike-transit" option for commuters needing flexibility, convenience, and access to transit systems. Using a folding bike on a bike-transit journey allows users the ability to board transit vehicles and seamlessly complete first-last mile connections. The versatility of a folding bike is appropriate when inadequate storage or bike theft is a concern. A foldable bike allows users to easily transport the bike using less space when the bike is “folded” into a compact size. A common concern is that people are unwilling to walk a half-mile to a transit station or stop, the inclination then, tends to be that individuals drive to a transit station. For bicyclists, trains or buses are not always capable of providing capacity to accommodate full sized bicycles. Foldable bikes begin to alleviate some of these concerns.

Most transit agencies allow folding bikes aboard their trains or buses, even during peak hours. Providing incentives to encourage folding bike usage can address capcity issues and assist with the bicycle-transit relationship. A Bicycle Subsidy Plan developed for Los Angeles County in California will soon deploy 700 folding bicycles, in connection with transit in Pasadena, CA and the surrounding areas. The goal of the Plan is to encourage and provide guidance for launching a full-scale program. The plan attempts to determine demand for folding bikes based on certain indicators such as location, socio-demographic factors, and different incentive scenarios that can then be applied when designing individual programs to expand bike-transit options. (Silver, 2011). Figure 1, demonstrates the size and ease of carrying a folding bike on to a train.

Figure 1: Boarding light rail train with folding bike in Los Angeles, CA

Transit-Oriented Development (TOD)

Transit-oriented development (TOD) is often defined as higher-density mixed-use development within walking distance, or a half mile, of transit stations. TOD is about creating attractive, walkable, sustainable communities that allow residents to have housing and transportation choices. Residents strive for convenient, affordable, pleasant lives with places for kids to play and parents to grow old comfortably. Communities wishing to pursue TOD projects should also increase “location efficiency” so people can walk, bike and take transit. Boosting transit ridership helps to minimize traffic congestion.

The Rosslyn-Ballston Corridor in Arlington, VA, illustrates how TOD can accommodate tremendous development in a way that benefits residents. The Corridor is built on the notion that creating communities with easy access to transit benefits commuters, private industry, and the community. Once a declining low-density commercial corridor 30 years ago, the local government decided to focus development around five closely spaced rail stations. The results are extraordinary. Despite the enormous amount of development that has occurred, single-family neighborhoods have been preserved just a short walk away, and there has been only a modest increase in traffic. Added benefits have included assessed value of land around stations increasing 81% over 10 years, rising transit use supported by the fact that 50% of residents take transit to work and 73% walk to stations. (Reconnecting America, 2007). By co-locating dense urban dwellings and retail around the local transit corridor, what historically was pasture land only a few decades ago is now a thriving urban center due to transit development and progressive land use policy.

Traveler Information Systems

Traveler information systems provide real time, updated information to users for all modes of transportation. Information can be accessed via handheld personal digital assistants ("PDAs"), on-street kiosks, conventional computers and smart phones. These systems provide maps, text versions of schedules, and arrival times. The information allows riders to track bus or train locations and arrival times with the click of a mouse or PDA. Unlike traditional bus schedules, these systems allow the rider to track the moment-to-moment status of any bus or train, so they know the exact time when their ride will be at their destination. Instead of waiting at the bus stop, a passenger can use the service to help them spend their time the way they want to—running another errand, finishing up another project, or simply waiting inside.

Technologies which help alleviate the realities of the first-last mile dilemma include pre-trip itinerary planning using the web as information kiosks, real-time bus and train arrival systems, and travel announcements. Through the technology of Google Maps, Google's Transit Trip Planner integrates station, stop, route, and schedule information to make trip planning quick and easy. In December 2005, Google launched Google Transit on Google Labs. Now mainstream, the service calculates route, transit time, cost, and can compare the trip to one using a car. The search engine now publishes schedules of more than 475 transit agencies world-wide through its Google Maps. (Jaffe, 2012).

More importantly, new research is proving that information systems providing transit data and schedules to the public can assist in mode shift and increasing transit use. In a recent study which evaluated Chicago's Bus Tracker services, researchers have concluded that modest gains in ridership can be attributed to these services and efforts compounded when targeted to non-transit users. (Tang, 2012).

Innovative Mobility Strategies

Dynamic Ridesharing

Real-time ridesharing (also known as instant ridesharing, dynamic ridesharing, ad-hoc ridesharing, or dynamic carpooling) is a service that arranges one-time shared rides on very short notice. This type of carpooling generally makes use of three recent technological advances: GPS navigation devices to determine a driver's route, smart phones for a traveler to request a ride from wherever they happen to be, and social networks to establish trust and accountability between drivers and passengers (Oliphant, 2011).

These elements are coordinated through a network service, which can instantaneously handle the driver payments and match rides using an optimization algorithm. Real-time ridesharing is promoted as a way to better utilize the empty seats in most passenger cars, thus lowering fuel usage and transport costs. It can serve areas not covered by a public transit system and act as a transit feeder service. It is capable of serving one-time, as well as recurrent, commute trips. Furthermore, it can limit the volume of car traffic, thereby reducing congestion and mitigating traffic's environmental impact. (DeCorla-Souza, 2011).

While most people understand the benefits and efficiency of carpooling, it is typically not flexible or convenient enough to meet the demands and busy lives of today's commuters. However, companies such as Avego Shared Transport use intelligent transportation systems to make carpooling more flexible, reliable and convenient. Avego uses the latest in location and communication technology to provide a marketplace for drivers to offer their empty seats to other people in real time. This on-demand, real-time ridesharing system, which is now available as a free iPhone application, incentivizes drivers to run their car as a bus, saving money by accepting ride requests from riders along their route. Data and specific results are not available at this time, however many pilot programs involving Avego and aspects of dynamic rideshare are currently being conducted. In Northern Virginia, a 6-month pilot program was recently launched that hopes to recruit at least 500 drivers and 1000 riders. The goal for that program is to reduce at least 120,000 SOV trips. (Tadej, 2012)

Electric Bikes

Electric bikes have entered the mainstream. Some replace pedal power with an electric motor, others require pedaling but amplify a cyclist's efforts. San Franciscans will soon have a new option for navigating the city's notorious hills without breaking a sweat or resorting to a car. A Federally-financed electric bike share program will begin this year.

The U.S. Federal Highway Administration's Value Pricing Pilot Program awarded $1.5 million for the initiative through the San Francisco Metropolitan Transportation Agency, the project's fiscal sponsor. Ultimately the money will go to the local nonprofit City CarShare, which plans to integrate the e-bikes and trailers with its existing car sharing service. Funding will also go to the Transportation Sustainability Research Center at University of California, Berkeley, which is responsible for assessing the impact and lessons learned from the project. (Garthwaite, 2012).

Electric Car Sharing

Car-sharing programs, now common around the world, allow people to have on-demand access to a shared fleet of vehicles on an as-needed basis. Usage charges are assessed at an hourly and/or mileage rate, in addition to a refundable deposit and/or a low annual membership fee. Car-sharing is similar to conventional car rental programs, with a few key differences between most programs: a) system users must be members of a car-sharing organization; b) fee structures typically emphasize short-term rentals rather than daily or weekly rentals; c) vehicle reservations and access is "self-service"; d) vehicle locations are widely distributed rather than concentrated; and e) vehicles must be picked up and dropped off at the same location.

In Paris, however, carsharing is being revolutionized through a system called 'AutoLib' that launched last fall. Participants can rent tiny electric "Bluecars," similar to renting a bike through a bike-sharing program. Once you register and get an ID badge, you can pick up a car at one of the 1,200 parking spaces–complete with charging stations–around the city. You simply use your badge to unlock the vehicle. The promise is that you can drive up to 150 miles on a single charge. They rent for roughly $13 a day or $20 a week. City officials say they hope to have 5,000 of the little cars buzzing around Paris' streets by next year. (Société Autolib', 2012)

Automated Transportation Networks (ATN)

Automated Transit Networks (ATN), often described as Personal Rapid Transit (PRT) or Podcars, are once again an emerging transportation technology. ATN, transports passengers non-stop along a dedicated right-of-way, using minimal land and energy. Electromagnetically powered, these systems can utilize renewable energy sources and have a tiny footprint.

The concept of ATN has been around since the 1950's, developing out of post WWII suburban growth, but was typically the product of aerospace companies. Most systems never made it past testing due to cost, loss of local or Federal funding and interest, and technology limitations. Some of this has changed, and interest is once again on the rise as evidence of efficient operations and lower implementation costs are realized.

A version of ATN has been successfully operating in Morgantown, West Virginia, for more than 35 years. New systems are up and running in Masdar City, UAE (2010) and at Heathrow Airport in London (2011). ATN systems are currently under construction in Suncheon Bay, South Korea, and Amritsar, India, and under consideration in many other places throughout the world.

Average weekday ridership for the Morgantown PRT reaches 15,000 trips, and the system can accomodate close to 7,000 passengers per hour. While most of the trips account for studnent travel, recent data shows an increase in the use of the system by the general community. (Kierig, 2012). As demonstrated in Figure 2, the Morgantown PRT system has become a part of the historic city.

Figure 2: The Morgantown, WV PRT system is a unique and easy-to-use transportation.

Today, there are a wide range of applications for ATN, including airports, cities (especially feeder/distributor) & campuses. Recent studies show significant benefits to existing bus & rail services when they are supported by an on-demand ATN network. For example, a study conducted in Gateshead, UK concluded that a 21km PRT network serving the inner city would increase the use of rail travel by 168% in the peak and 232% in the off-peak. (Lowson, 2012).

Emerging Innovations

Increased mobility options will allow transit to better compete with the auto for a reliable, efficient, and enjoyable trip. Access to existing public transit will also leverage existing systems and investments. A host of emerging technologies are being developed or implemented around the world to encourare transit use, and ultimately the reliance on the SOV. The reemergence of the jitney and new taxi services are only a few examples.

A jitney, or share taxi, is a transport mode that falls between taxis and buses. These vehicles for hire are typically smaller than buses and usually take passengers on a fixed or semi-fixed route without timetables. Jitneys may stop anywhere to pick up or drop off passengers. Often found in developing countries, vehicles used as share taxis range from four-seat cars to minibuses and are often owner operated.

Today, after decades of regulation limiting such operations, the jitney is making a comeback. Jitneys can utilizie new technologies and fill the gaps where conventional transit struggles due to funding or other issues. For example, The Wave is a high quality, fixed route, fixed rate, permitted jitney service. The Wave runs in Houston, Texas connecting people and places, while helping to resolve the area's immediate & critical needs. The service promotes ease of movement and transit use, while also helping to reduce congestion and improve public safety.

Taxis continue to play an integral role within the urban matrix by providing on-demand mobility for users. However, creative operations are now emerging to assist transit operations in more dispersedly populated areas and at off-peak hours when transit runs less frequently. New technologies and the entrepreneurial spirit are also enhancing services and expanding mobility options for customers. In Chicago, for example, a taxi driver opened a Twitter account to comment on all things related to transport. What started out as a venue for discussion has turned into an everyday business tool. Today, he takes ride requests through Twitter. If available, he will pick you up and take you to your destination, offering discounts through social media from time to time. (Cheng, 2012).

Other innovations, which were long held as concepts, are currently being discussed. Cities in Asia are incorporating industrial sized escalators for pedestrian movement in topographically challenged areas. Communities are turning toward alternative vehicles such as low-weight, battery-operated electric carts to shuttle riders in pedestrian zones. Concepts such as movable walkways, raised guideways supporting human, pedal-powered vehicles are being designed for implementation.

Conclusion

Urban transport is ever changing, as evidenced by the evolution of services and the prospects of innovation discussed. Innovation stems from the demand that users have for efficient, reliable and safe mobility. Transit is often the most efficient mode of transport. However, transit is in constant competition with the SOV as the most convenient door-to-door option. As users demand both efficiency and ease, transit must continue to innovate by developing and encouraging solutions that solve first-last mile access. Solutions exist, while other concepts remain in various stages of demonstration. Cities, jurisdictions and agencies will need to create compelling and seamless systems for users. By providing safe, convenient mobility choices to access transit, reduction in VMT and ultimately harmful GHG in the environment can be alleviated.

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Public transportation systems for urban planners and designers: the urban morphology of public transportation systems

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Abstract

The ambition in European cities is to create an integrated, multimodal transportation system which fully exploits the potential of public transportation. The “compact city” and “multimodality” are new fashionable buzzwords. But many, especially smaller cities in Europe developed rapidly in the second half of the 20th century in the years of rapid motorization and decentralization of cities. These cities were designed for the private car and are dominated by individual mobility. The change from a city for a private car to multimodal public transport cities demands major urban transformation.

In this article the public transportation systems are seen through a perspective of a morphological concept in urban planning and design established by Kevin Lynch. The public transportation infrastructures are combinations of *paths* and *nodes* that disperse distinctive attractiveness pattern of *desirability cores* that shapes the neighborhoods. There are many examples of integration public transportation systems shaped the urban form. A “public transport city” is a section of a city that historically adapted to specific public transportation systems. There are four distinctive *public transport cities* which unfold consistent and unique urban form and mobility patterns. Each *public transport city* has different urban morphology with weaknesses and strengths important for urban designers, planners and developers especially when there is a need to introduce new public transportation systems in urban areas dominated by private cars.

Introduction

The European response to the urban challenge of sustainable development is traced through the documents of the European Commission (EC) on urban environment, sustainable cities and urban transport since the 1990s. Derelict land, urban sprawl and quality of the urban environment were identified as major urban problems (EC, 1990:4) and the *compact city* and *green city* emerged as solutions. The *compact city* emphasizes urban intensity by setting urban boundaries, pursuing urban renewal and densification within these boundaries and connecting urban areas with public transportation systems. The urban expansion is halted to protect the surrounding environments thus creating a strong contrast between the city and the nature. The *green city* relies on environmental design, innovation and development of communities in order not to disturb the natural rhythms and landscapes (EC, 1998, pp. 6-7). The *compact city* revolves around urbanity and multimodality, historicity and creativity. It favors architectural heritage, by respecting rather than imitating the old, greater diversity by mixed uses and solving urban problems within existing boundaries of the city (EC, 1990, pp.30). The argument is that urban density and diversity are more likely to result into people living close to work places and services that are required for the everyday life (EC, 1990, pp.40). The ambition is to make the private car an option rather than a necessity (EC, 1990, pp. 30) by creating integrated, *multimodal transportation systems* which fully exploit the potential of public transportation (EC, 1997, pp. 11-2).

The “compact city” and “multimodality”, “intensification” and “mixing” are new fashionable buzzwords urban and regional planning throughout Europe, but the realities are different. Many, especially smaller towns and cities in Western and Northern Europe developed rapidly in the years of rapid motorization and decentralization of cities. The trend of urban decentralization spread eastward and southward during the second half of the 20th century (Hall, 1997). In the countries of Western and Northern Europe the modernism recipe of inhabiting, working, recreation and circulation advocaed by Le Corbusier and CIAM (Congrès International d'Architecture Moderne) was vigilantly executed. The cities were shaped by an ideology of large scale suburban projects, controversial reconstructions and modernizations of the industrial and historical urban cores and major investments in roads and motorways. The Western and Northern European “modern city” developed as archipelagos of shopping districts, residential neighborhoods and industrial zones segregated by vast green areas for recreation or agriculture. The *modern cities* were designed for the private car by lavish parking regulations, traffic separation and extensive road hierarchy and today they are dominated by individual mobility.

The public bus emerged as preferred often only alternative to the private car during the modernization of European towns and cities. Buses were conceived as flexible and universally applicable. The buses use the same roads as the automobiles and trucks. They easily overcome obstacles and eventually reach their stops or stations by alternative routes. There is no place on the road network that is inaccessible by bus. The flexibility and universal overuse of buses prove to be devastating for public transportation in the smaller cities where the entire networks were planned with buses. Ironically the general perception even today is that there is no need to plan for the bus. The urban planners and designers usually pin a bus stop and declare public transport accessibility by drawing a 400m radius. The buses are usually forgotten in the planning processes and as results of this negligence there are often lonely bus stops misplaced on motorways. The second more challenging problem is the competitiveness of buses especially in the smaller towns and cities. The smaller towns and cities today are equally fragmented and dispersed in their regions and interconnected by bypassing motorways as the larger cities in Western and Northern Europe. The buses serve long distances and they perform very poorly on the road hierarchies and motorways. They need busy streets and need to stop often. They need to pass though the neighborhoods that are designed with roads that allow traffic separation.

There is a need of changes to make the buses visible in the urban planning and design processes. A neighborhood within a 400m walking radius to a bus line with frequency of one bus per hour is hardly a viable public transportation alternative. Public transportation is often peripheral in urban planning and design. However the position of the private car on the other hand is as strong as always. For example the number of parking places is one of the strongest regulations policies.

The urban morphology of public transportation systems

Urban morphology revolves around urban form and the processes of formation and transformation of urban areas. It is a multidiscipline between architecture and urban design, geography and history, economics and politics. The scope of the definition varies from researching physical activities and form in two or three dimensional space to a study of processes, knowledge, power and actuation (Friedman, 1987). In its narrower definition within architecture and geography, urban morphology puts emphasis of study of physical form and processes of its emergence and transformation. There are many schools, traditions and scholars even in the narrower definition of urban morphology. The British or “Conzenian school” originates from the work of geographer Michael R.P.G Conzen. Even though theoretically the urban form is framed as a process, a temporal change of streets, plots and buildings (Conzen and Conzen, 2004), the scholars primarily focus on the two-dimensional extend and representation of urban areas through historical changes in planning practice and architectural styles. In contrast to the British school, the Italian school has strong architectural background inherited from the work of the Italian architect Saverio Muratori and his followers. The Italian cities changed architecturally throughout the history and the “Muratorian school” focuses on three-dimensional transformation, design, representation and interpretation of the architectural detail of the urban form (Caniggia & Maffei, 2001).

The vantage point within the narrower urban morphology field is the American urban planner Kevin Lynch. With Lloyd Rodwin, he set a morphological tradition to look at the cities as *adapted spaces* and *flow system* (Lynch and Rodwin, 1958) or *spaces* and *channels* of flows. The *activities* occur and recur in *adapted spaces* that are linked by *communications* within *channels* (McLoughlin, 1969). Within the framework of urban space and flow, Lynch defined five urban elements that are cognitively recognizable: *paths*, *nodes*, *districts*, *edges* and *landmarks*. *Paths* are the channels along which the observer customarily, occasionally or potentially moves. They may be streets, walkways, public transportation lines, canals, railroads. *Edges* are the linear elements not used or considered as paths by the observer. They are the boundaries between two phases, linear breaks in continuity: shores, railroad cuts or walls. *Districts* are the sections of the city, conceived of as having two-dimensional extent, which the observer mentally enters "inside of" and which are recognizable as having some common, identifying character. *Nodes* are points, the strategic spots in a city into which an observer can enter and which are the intensive foci to and from which he is traveling. They may be primarily junctions, places of a break in transportation. *Landmarks* are another type of point reference, but in this case the observer does not enter within them, they are external: building, sign, store or tree (Lynch, 1960, pp.4).

The Lynch's urban elements are conjoint by another *district* element and the *edge* element is modified to represent the morphological interrelationship between neighborhoods and public transportation infrastructures (Figure 1). The *desirability cores* are inspired by Stephen Marshall's research on urban patterns (Marshall, 2005, Marshall & Gong, 2008). They show the peaks in desirability or attractiveness in one *district* in regard to the exits from the public transportation station or stop areas that are represented by *nodes*. The urban areas around stations are also represented by *districts* with distinctive urban form. The challenge for urban designers, planners and developers when there is a need to introduce new public transportation systems in urban areas is to integrate the urban form with the *desirability cores* of the public transportation infrastructure and consider their barrier effects.

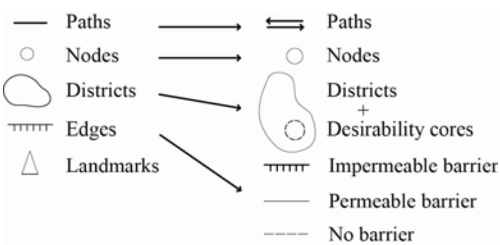

Figure 1: Modification of Kevin Lynch's urban elements to fit the representation of the morphological interrelationship between neighborhoods and public transportation infrastructures.

The *desirability cores* have stretchy borders. They can shrink or extend depending on the design of the urban environments. They start when a person changes transport mode from public transportation to walking and steps out on a public transportation stop and station. The *desirability cores* are principally nodal. The exit door of a bus, tram or train is an initial vantage point in the space of a *desirability cores*, but they can elongate in amoebic shape if it is continues in attractive and walkable urban environment. For example flows and crowds of people trigger subconscious movement of a person in a crowd, extend the line of sight and add a sequence of new prospects.

The public transportation and cities

The urban form depends on the transportation infrastructures. The cities adapt, integrate or isolate transportation infrastructures. The unattractive motorways for example bypass the cities, but are very unattractive and the urban areas dispersed along the motorways, but separated by green areas. The bus lines and tramways elongate the cities by highlighting streets as urban corridors. The railways interconnect and disperse urban areas as beads on a string. By their effect on development on cities, there are basically three principal public transportation technologies (Figure 2): 1) *on streets* (buses and trams); 2) *completely separated, either elevated or on the ground* (buses or trains on heavy railways or heavy busways); 3) *underground* (buses or trains in subways or tunnels); contributed by a hybrid of the three: 4) *partially separated on ground* (buses and trams on light railways or light busways). The designation X shows the anchor whereas (X) ranges of the various public transportation infrastructures as technologies. I abducted the common distinction in transportation (*light* versus *heavy*) to define types of infrastructures. *Heavy* means always *complete* or *full separation* regardless if it is a bus or rail system. In reality there are only few examples of heavy busways whereas the railways naturally carry the *heavy* attribute. The *light* attribute is for systems are *partially separated*, or are *partially* on street or *partially* fully separated and the light railways and light busways also have same effect on urban form and structure.

	On streets in traffic	Dedicated lane *on streets*	*Partially separated on ground*	*Fully separated on ground or elevated*	In tunnel or *underground*
Bus line	X	X	(X)		
Light busway (BRT)		(X)	X	(X)	
Heavy busway (BRT)			(X)	X	(X)
Tramway	X	X	(X)		
Light railway (LRT)	(X)	(X)	X	(X)	(X)
Heavy railway				X	(X)
Subway					X

Figure 2: Principal public transportation infrastructures and *technologies*

Two technologies concentrate over specialized infrastructures and excel either at urban scale as *public transportation on streets* or at regional scale as *fully separated on ground or elevated public transportation*. The *underground public transportation* excels on both scales but at very high cost. The hybrids, *public transportation partially separated on ground* also tend to have wide span claiming both domains with tradeoffs of cost, speed and capacity. Each public transportation technology enables unique pattern of *desirability cores* beyond the network of *paths* and *nodes*. These morphological consistencies and regularities as four principal *public transport cities* (Figure 3): 1) the elongated and interwoven city; 2) the city of pearls; 3) the networked city; and 4) the compact city.

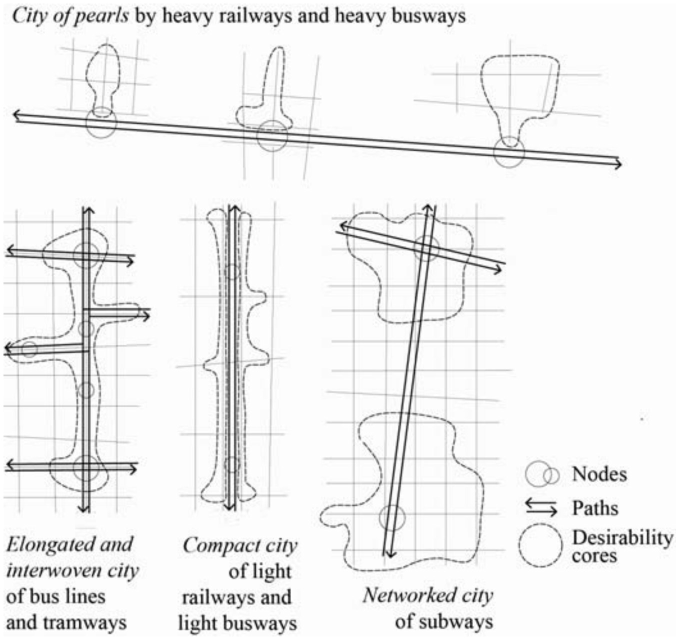

Figure 3: The principal *public transport cities*

In reality there are no exclusively or distinctively *elongated and interwoven cities*, *cities of pearls*, *networked cities* or *compact cities* according to the classification above. The cities are rather combinations of *public transport cities* that overlay and coexist simultaneously as *public transport metropolis*. The large Western and Northern European cities like London, Paris, Berlin, Copenhagen, Stockholm or Helsinki are example of *public transport metropolises* that throughout the history integrated continuously new public transportation infrastructures and technologies. Stockholm is one example. Stockholm's subway and heavy railways structuralize *networked city* and *city of pears* in its region, while the buses *elongate and interweave* its urban cores into corridors

Light rail transit (LRT) and bus rapid transit (BRT) are in the core of the *multimodality* advocacy for the *compact city*. They are identified as universal solutions for public transportation at urban and regional scale especially for the smaller European towns and cities. There are many new neighborhoods in Europe developed along multimodal streets with light railway or light busway as a median. There is a wide replication of a single compact city model of urban corridors along partially separated public transportation.

The morphological effect of the *public transport cities*

According to Kevin Lynch we make mental maps of territories as networks of *districts* accessible by *paths* through a sequence of *landmarks*. He refers to the concept as wayfinding (Lynch, 1960). The *public transport cities* historically unfolded consistent and unique cityscapes and networks of interwoven or isolated urban nuclei and corridors (Stojanovski et al., 2012). These historical artifacts are summarized, illustrated and discussed at urban and regional scale. The urban scale is determined by walking and sight. The regional scale is defined by mobility and cognition of accessible territories by availability and speed of motorized transport modes.

The elongated and interwoven city of the bus lines and tramways

The *elongated and interwoven city* of the bus lines and tramways emerged in the 19th century when the buses and trams struggled on the busiest streets forming attractive urban corridors. The buses and trams followed the people and the businesses. The additional bus lines and tramways folded new layers of people and businesses over the existing. The dense 19th century cities became denser and more congested as the *public transportation on streets* added capacity. The urban areas are fused and interconnected by bus lines or tramways. The desirability along *public transportation on the streets* is the street itself as elongated *desirability core.* The bus lines and tramways are fully integrated in the city without barrier effects and shape *urban corridors*. The distances between stops are often too small to achieve disturbance in attractiveness along (Figure 4).

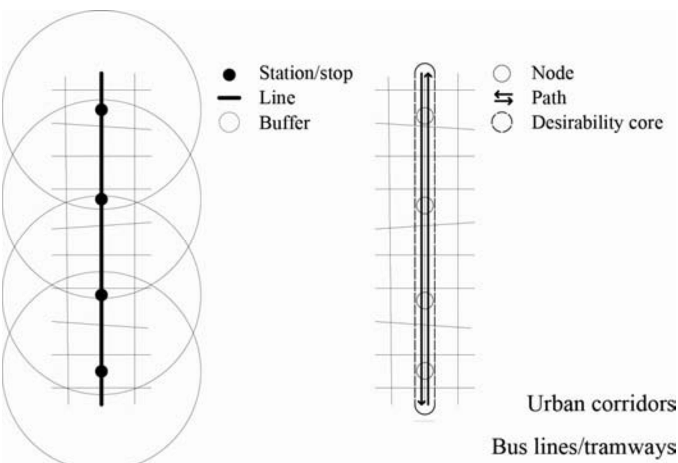

Figure 4: The *desirability cores* of the bus lines and tramways. The representation with *paths*, *nodes* and *desirability cores* inspired by Kevin Lynch on the right of the common representation of lines, stations or stops and buffers

The city of pearls spread out by the railways

The railways had profound effect on the urban form from the 19th century. Completely separated from the other traffic the trains are fast transport modes enabling warp transports which temporally glue distant place together and blur the spaces in between. Unlike the closely located bus and tram stops on the streets, the stations are nodes, *pearls* *on an* impenetrable *string*. They are placed at distances that prevented overlapping buffers. This gives total and direct control over the accessibility between two places and enables temporal convergence of distant places. Every station opened a new spatially far, but temporally close urban area and the heavy railways or heavy busways enact monopoly over the direct access. The heavy railways or heavy busways unfold *urban nuclei*. The desirability around train stations is nodal and the attractiveness can vary depending if the train stations are on the ground, elevated or are termini. The position of the station exists, the shading and permeability profoundly affects the pattern of *desirability cores*. They have unique urban attractiveness which often starts where the station ends as a *node*. The heavy railways or heavy busways are segregated from the city and regardless if they are on the ground or they are elevated they cause severe barrier effects (Figure 5).

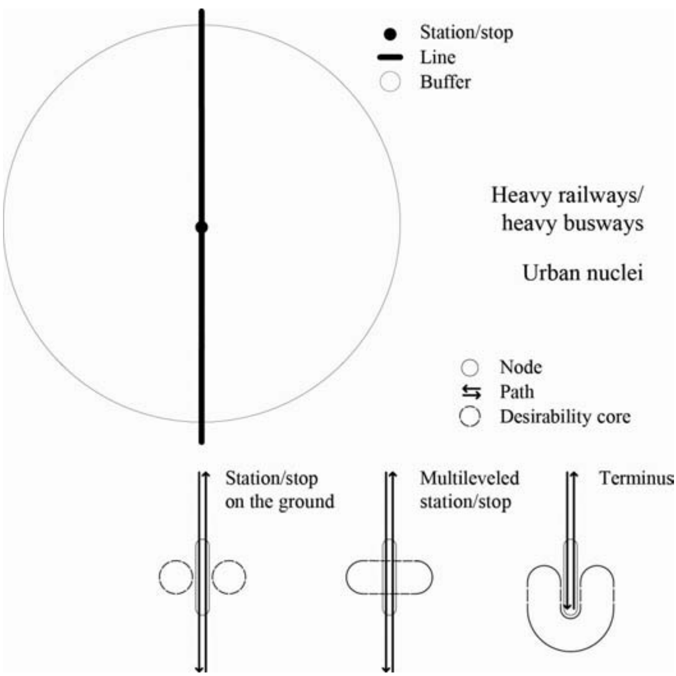

Figure 5: The *desirability cores* of the heavy railways and heavy busways. The type of station and the arrangement of exits from the station define the *desirability cores*.

The networked city above the subway

The subways act much like monumental baroque diagonals and boulevards, just invisible to the city above. They interconnect and fuse spaces similarly as the railways. At terrible expense, they preserve the city above, protecting the traditional urban fabric and historical heritage. They rival or outperform any surface transport in the congested urban cores and they do not cause visual impacts as the elevated railway systems. They profoundly affect the vibrancy of urban life above, increasing speed and adding capacity that does not disturb the traffic flows on the ground. The subways have nodal attractiveness and the *desirability core* that depends on the exits and entrances from the underground. The exits are conjoint in amoebic *desirability core* and the illustration below is rather schematic. The station itself is part of the *desirability core* with urbanity and attractiveness that blends with the city above. The lack of barrier effects on the ground and underground produces *desirability core* as multileveled space (Figure 6).

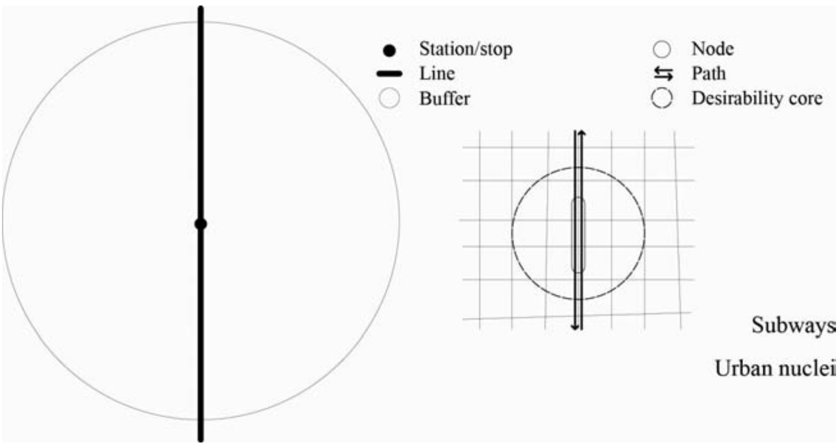

Figure 6: The *desirability cores* of the subways. The *desirability cores* of the exits and entrances that blend with the city fuse in one *desirability core* as urban nucleus.

The compact city along the partially separated railways or busways

The light railways or light busways are usually realized as median on boulevards or major streets. As medians they are often partially segregated from the city and that causes some barrier effects. The urban design details define the strength of separation: from accentuation of the busways or railways by curbs to elongated parks and impermeable fences. The *compact city* advocacy revolves around BRT and LRT and the tendency is to recreate the traditional European city. But the urban form is much different than in the traditional urban cores. The blocks are wider and the segregated sections of the busways and railways block wide strolling over the boulevards. The attractiveness along the partially separated light railways or light busways is a compromise between the elongated core of the bus lines and tramways and the barrier effect of the heavy railways or heavy busways. There are two elongated cores of highest attractiveness centered on the sidewalks parallel to the light railway or light busway (Figure 7).

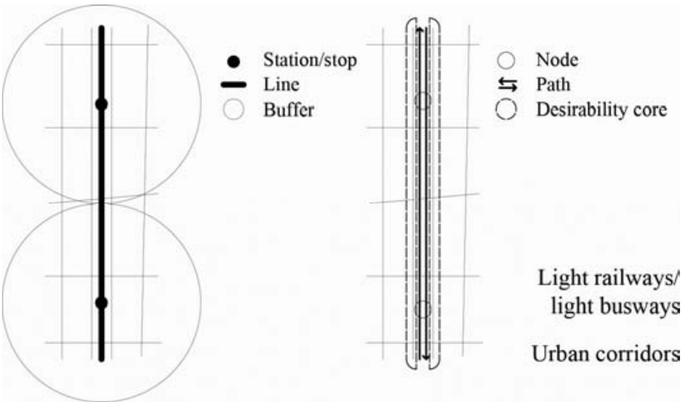

Figure 7: The *desirability cores* of the light railway or light busways. Two elongated desirability cores are within one urban corridor.

The public transport cities at urban and regional scale

The motorized transport allows for convergence of space and time and the urban boundaries today are more a variable of time, than distance. The public transport cities here are present from motorized and walking perspective, at urban and regional scale. There are constrains in and temporal invariants in travel behavior (Marchetti, 1994). The travel time budget is the time that we spend traveling during one day. The empirical research of travel behavior shows that it varies between 1 and 2 hours per day (Zahavi, 1974). The invariant of 1 hour travel time per day is known as Marchetti constant and it is considered as determinant of the radius of the city (Marchetti, 1994). Here it is used to theoretically calculate the rounded distances that the *public transport cities* can reach. At regional scale, the *public transport cities* unfold patterns of urban *nodes* and *corridors* within some urban radius (Figure).

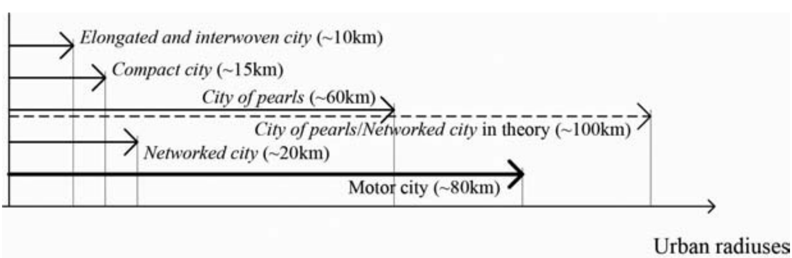

Figure 8: The urban radiuses of the four principal *public transport cities* compared to the motor city. The convenience of the private car and the speedy motorways allow daily travel distances up to 80km in Sweden (Hagson & Mossfeldt 2008).

The *public transportation on streets* accelerates the urban life and enables elongation and interweaving of the urban flows in cities into attractive *urban corridors*. The *omnibuses*, *cable cars*, *horse cars*, *trams* or *streetcars*, *motorbuses* or *commonly buses*, *trolleybuses* or *trolleys*, are *public transportation on streets*. They are all modification of a same technology. If we consider capacity and speed they did not change dramatically with different propulsion systems. Hindered by the traffic on the streets, they are slow transport modes reaching 10-20km/h average speed, thus delimiting the length of their lines to roughly 10km. The radius of the *elongated and interwoven city* is therefore limited to around 10km. The longer bus lines or tramways are usual, but they are not as attractive in regard to the travel time budgets of Zahavi or Marchetti constant. The lack of speed of the *public transportation on streets* is completed by a longitudinal attractiveness, urbanity and short walking distances. The buses and trams add vibrancy on streets, give pleasant urban vistas and create mobile public spaces.

The *fully separated public transportation* orchestrates discontinuity of urban fabric and regional existence as temporal convergence of distant places. The railways spread a pattern of *urban nuclei* in regions and usually use the shortest distance, by almost direct lines, to travel between them. The *trains* reach over 500km/h today. The high speed railways (HSR) operate at average speeds of around 200km/h. With these speeds, theoretically, the *city of pearls* can extend over 100km. The urban radius of the *city of pearls* is set to 60km here that roughly corresponds to the lengths of the suburban railway lines in the large European cities, for example Pendeltåg, RER or Overground lines in Stockholm, Paris or London.

The *public transportation underground* strengthens the poly-nucleated agglomeration of the historical cores of the cities by adding concentration and quick getaways. They act much like monumental baroque diagonals and boulevards, just invisible to the city above. With speeds of more than 30km/h they can open, connect or establish *urban nuclei*. If we consider the average speed of subways in European cities the radius of a *networked city* can reach 20km, but the theoretical size of a *networked city* is practically comparable to the *city of pearls*. The costs of tunneling within a radius of 100km can be incredibly high.

The *partially separated public transportation* makes a tradeoff of the barrier effect of the public transport infrastructure and the attractiveness of the *urban corridors*. LRT and BRT on light railways or light busways have an average speed of 20-30km/h. The speed of the buses and trams on light railways or light busways is higher than *public transportation on streets*, but it is not possible to achieve high speeds because of the conflicts on intersections. It is also not possible to have high frequencies too, because it can cause stops at intersections.

At urban scale the public transport infrastructure produce *edges* and cause barrier effects. They do not only influence the creation of paths and flows of pedestrians, but also the patterns of *districts*. This knowledge is of particular interest those that want to plan livable places.

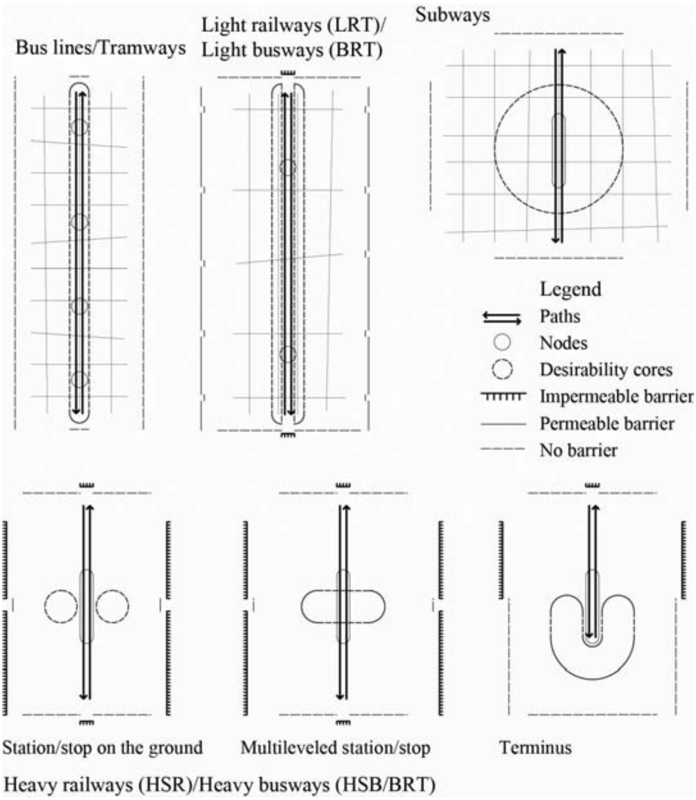

Figure 9: Permeability and barrier effect of different public transportation infrastructures

The competitiveness to the private car

There are many urban areas in the Europeans towns and cities that are reliant on the private car. The challenge is to introduce competitive public transportation system that can replace the car. John Urry argues that the “public mobility” pattern of the 19th century will not be re-established in the future simply because the private car “produced and necessitated individual mobility based upon instantaneous time, fragmentation and coerced flexibility”. The post-car system “will substantially involve *individualized movement* that automobility presupposes” (Urry, 2007, pp.285).

The real challenge for urban and regional designers, planners and developers is to create a network of urban areas interconnected by public transportation systems that can compete with the instantaneity and flexibility of the car. It is not a challenge to design public transportation systems, but cities where it is possible to take a slow and quick bus, direct or detouring. The knowledge of public transport cities, their weaknesses and strengths can be important. Each *public transport city* revolves around distinctive public transportation infrastructure and pattern of *paths* and *nodes* that has to be integrated with the city. They *public transport cities* can be superposed over each other and hybridize in many variations.

The competitiveness of the *public transport cities* with the *motor city*, the city of the private car, is considered here simplistically from narrow morphological standpoint by comparing infrastructures and travel speeds and times on different infrastructures. The competitiveness is usually calculated by travel time ratios, which are defined as the quotient of the travel time by private car and public transportation between same origins and destinations in the city. The empirical evidence from Stockholm's region shows that if the travel time ratio is 1-1.5, the share of the public transport is 50-70% (SLL, 2001). When the travel time and costs of a between a private car and public transport journey are equal, there are other factors like comfort or attitude that decide, but there are competitive public transportation alternatives. For easier calculation there is a table that shows the ratios in travel time speeds between different infrastructures (Figure 9).

			Car speeds (km/h)			
			Motorway	Wider streets	Normal streets	Smaller streets
			70-100	30-70	30-50	20-40
Bus/ train speeds (km/h)	Motorway	50-70	1-2	0.4-1.4	0.4-1	0.3-0.6
	Wider streets	10-30	2.3-10	1-7	1-5	0.7-4
	Normal streets	10-20	3.5-10	1.5-7	1.5-5	1-4
	Smaller streets	10-15	4.6-10	2-7	2-5	1.3-4
	Light busway/railway	20-30	2.3-5	1-3.5	1-2.5	0.7-2
	Heavy busway/railway	30-200	0.3-3.3	0.2-2.3	0.2-1.7	0.1-1.3

Figure 10: Travel speed ratios on different transportation infrastructures

The hierarchy of roads is described from European perspective as motorways, wider, normal and smaller streets. The motorways are segregated and have speed limit of 100km/h. The wider streets have 4 lanes and more (speed limit 30-70km/h), the normal streets between 2 and 4 lanes (speed limit 30-50km/h), whereas the smaller streets have 2 narrow lanes (speed limit 30-40km/h). Travel speed ratio is only a theoretical measurement showing the quotient of the private car and public transport speed. In practice the travel time is calculated as *perceived* that includes walking, waiting, in vehicle, transfer and egress time which are weighted by coefficients. The *perception* of waiting time is usually double than the time in vehicle and the *perceived time* can increase dramatically with all the penalties for walking, transfers and waiting. The table shows how much a motorway can make a difference in the competitiveness in one urban region even without taking in consideration penalties for waiting, walking and transfers in public transportation. Being 10 minutes in a car on a motorway would mean from 23 to 50 minutes on a bus or tram on light busway or light railway or between 3 to 33 minutes on a bus or train a heavy busway or heavy railway.

Conclusions

The private car establishes a flexible and convenient system that is deeply rooted beyond the need of movement and transportation in economy, society and culture. It can be used for slow and fast transportation, for short and long distances, to socialize, to dream about. It is available around the clock (Urry, 2004). A high share of public transportation can happen only if the public transportation systems are equally integrated with cities, everyday life and fantasy and vice versa. Seeing morphologically it is important to understand the competition on public transportation through simple, but elementary infrastructural rules of *nodes*, *paths* and *desirability cores* at urban scale and possibility to reach urban areas at regional scale. It is important to start with a vision of networked metropolis. There is a need of urban areas that might develop in future nuclei and corridors, designs of layers of speedy and slower public transportation systems and thinking about physical integration with the urban areas to begin with. In the end there is a need to consider the temporalities as availability and diversity as need of sightseeing and warp via sociabilities, spectacles and daily lives. The *desirability cores* are zones that interlink neighborhoods and public transportation infrastructures and systems and these are the most attractive zones in a future *public transport metropolis*. The *desirability cores* as urban details can be decisive urban catalysers, inducers and drivers for urban development around stops and stations.

Much of the advocacy in Europe revolves around *multimodality* and the *compact city*, where LRT and BRT are universally applicable solutions. If we look at the European history, the principle of mixing different public transportation systems at urban and regional scale worked fine. LRT and BRT as *partially separated* infrastructures are disadvantaged compared to the *fully separated systems*. They are urban systems that are too slow (20-25km/h) to compete with the private car at regional scale. To enable competitive BRT or LRT in the regions there must be incredibly harsh policies restricting car access and pursuing development of one *urban corridor* in the region. This is probably impossible in cities with already extensive road hierarchy, wide urban dispersal and regional existence. The alternative especially in the small town and cities is to aim towards a *public transport metropolis*, to superpose a *city of pearls*, a city of heavy busways and heavy railways, over the existing fragmented urban areas and to combine it with the other *public transport cities* which excel at urban scale. The challenge is not to network all the urban areas in the regions, but to develop certain urban corridors and nuclei. The *metropolis* can be realized even with sophisticated high speed buses on special heavy busways. BRT achieves higher frequencies with lower capacities, whereas the trains have lower frequencies with higher capacities. Higher frequencies with lower capacities fit much better the decentralized cities in Sweden or other countries in Western of Northern Europe.

There are many ways to represent and conceptualize urban form and public transportation systems. The concepts presented here are simplified from a perspective of transportation planning and engineering. The modified Kevin Lynch's morphology is representational. It is made to make visible and overlay even very flexible bus lines and put them aside the urban areas and land uses, plots, buildings and streets in the urban and regional plans. This visibility helps to see the urban flows, urban forms and their interaction on maps.

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Load-Based Life-Cycle Greenhouse Gas Emissions Calculator: Running Emissions Sensitivity Analysis

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This paper describes a running emissions sensitivity analysis of the US Environmental Protection Agency's (EPA's) MOVES2010b model at the project level through the implementation of the Public Transit Greenhouse Gas (GHG) Emissions Management Calculator. MOVES model running emissions for diesel transit buses were estimated for seventeen heavy-duty transit bus driving cycles across twelve different locations and meteorological conditions. The preliminary results examine the estimated annual diesel transit bus NO_X and CO_2e emissions. With an understanding of the scaled tractive power operating mode bin distribution of a driving cycle and the MOVES model emission rates, the annual emissions can be analyzed and compared. The results obtained from this sensitivity analysis indicate the potential usefulness of the Public Transit GHG Emissions Management Calculator for use in evaluating emissions across driving cycles and environmental operating conditions in a comparative mode.

INTRODUCTION

Due to the immense magnitude of the U.S. transportation network, greenhouse gas (GHG) emissions created by the transportation sector accounted for nearly one-half of the increase in total U.S. GHG emissions from 1990 to 2006 (US DOT, 2010). These GHG emissions pose a threat by contributing to widespread impacts including changes in global temperature and weather patterns, deteriorating ecosystems, and adverse health effects. To alleviate GHG emissions from the transit sector, Weigel (2010) developed a Public Transit Greenhouse Gas Emissions Management Calculator (hereafter referred to as the Calculator). The Calculator was designed to aid transit agencies by introducing GHG emissions alongside purchasing criteria for more environmentally conscious vehicle fleet planning. Past studies have calculated life cycle emissions and/or costs from transit vehicle operations, but with limitations such as lack of comprehensive region-specific data and narrow scope of propulsion technologies (Weigel, 2010). For buses, the updated Calculator allows users to choose from conventional spark ignition/compression ignition (SI/CI), hybrid electric, plug-in hybrid electric, battery electric and fuel cell electric vehicles. The fuel options for SI/CI and hybrid electric buses include conventional diesel, gasoline, compressed natural gas, hydrogen, as well as 2%, 5%, 10% and 20% biodiesel. In addition to transit buses, the Calculator is able to estimate and compare emissions for other transit vehicle types including vans, diesel-electric rail, and all-electric heavy and light rail. Interested readers may refer to Xu et al. (2013a) for a bus technologies GHG emissions comparison application, and to Xu et al. (2013b) for a fuel-cycle emissions per passenger mile example from bus and rail technologies.

To estimate life-cycle emissions the Calculator combines upstream fuel-cycle emissions using the U.S. Environmental Protection Agency's (EPA's) Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model as well as direct on-road vehicle operation emissions from EPA's MOtor Vehicle Emissions Simulator (MOVES) model. The upstream fuel-cycle portion of the Calculator will not be included in this sensitivity analysis, leaving only direct operating emissions.

The MOVES model calculates vehicle emission rates based on type of vehicle operation, falling within a defined operating mode "bin". For heavy-duty vehicles running emission rates operating mode bins are defined primarily by scaled tractive power (STP). A total of 23 operating mode bins based on STP, speed, and acceleration are defined for running vehicle exhaust emissions. 21 of the operating mode bins are defined in terms of STP within a range of speed classes; deceleration/braking is defined in terms of acceleration, and idle is defined in terms of speed alone. Two bins represent "coasting" where STP<0 and the remaining operating mode bins represent "cruise/acceleration" operations where STP ranges from 0 to 30kW/tonne or greater (US EPA, 2012). The vehicle operating characteristics, or the duration of time within each operating mode bin (specified by the driving cycles), are used to calculate emissions using the MOVES produced NO_X and CO_2e emission rates that are stored in the Calculator.

SCOPE OF SENSITIVITY ANALYSIS

This paper analyzes the sensitivity of outputs from the MOVES model through the implementation of the Calculator across varying locations and meteorology scenarios, and vehicle operating conditions. The scope of the sensitivity analysis focuses on running exhaust emissions from typical 12-meter heavy-duty diesel transit buses. Table 1 shows the twelve locations evaluated that are representative of a wide range of geographic and meteorological conditions. Temperatures and relative humidity values shown are MOVES model default inputs for the specified modeling location and season. The expanded range of temperatures and humidity of the locations assessed are meant to test the emissions modeling capabilities of the MOVES model as revealed through the use of the Calculator.

In addition to temperature and humidity, the Calculator also takes into account the effect of terrain on engine load and the resulting emissions. The terrain roughness coefficient included in the modeling approach helps to account for variations in vehicle energy consumption due to surface morphology. Hilly or mountainous terrain requires that vehicles expend greater tractive power on average than equivalent flat terrain for any normal driving schedule (i.e. speed vs. time). On uphill segments, vehicles require additional power to overcome gravitational forces (i.e. increase the gravitational potential energy of the vehicle). While both conventional and hybrid vehicles recover some of the expended energy on downhill segments, drivetrain losses ensure that this will never equal the energy expended on the uphill segment. In addition, conventional vehicles lose energy due to braking requirements on down-slopes. Hybrid vehicles recover a portion of this energy through regenerative braking.

To account for these additional loads, the Calculator includes a roughness coefficient that describes the typical degree of surface undulations associated with the topography of particular localities. This energy expenditure is modeled in the calculator as a continuous small positive grade that accounts for the average additional energy expenditure. Terrain roughness is categorized into flat, low, medium, and high. The default values are assigned by physiographic region and can be modified by the user to represent the actual roughness of the transit system routes. The assumptions on terrain roughness for the twelve selected locations are included in Table 1. The authors acknowledge that the listed terrain roughness may not be the most accurate representation of the local terrain, but rather, a demonstrative assumption that helps illustrate the combined effect of meteorological and geographical conditions on emissions.

Table 1. Analysis locations and meteorological conditions

Location	Modeling Season	Temperature (ºC)	Relative Humidity (%)	Terrain Roughness
Atlanta, GA	Summer (July)	30.7	53.8	Low
Houston, TX	Summer (July)	33.0	56.8	Flat
Detroit, MI	Summer (July)	28.8	51.6	Flat
Phoenix, AZ	Summer (July)	40.3	20.6	Medium
Richmond, VA	Summer (July)	29.8	57.5	Low
San Francisco, CA	Summer (July)	18.5	60.1	High
Boston, MA	Winter (Jan.)	-6.8	66.6	Low
Denver, CO	Winter (Jan.)	-9.4	58.0	Low
Miami, FL	Winter (Jan.)	15.2	83.2	Flat
Minneapolis, MN	Winter (Jan.)	-15.8	77.7	Flat
Dallas, TX	Winter (Jan.)	1.5	73.8	Flat
Seattle, WA	Winter (Jan.)	1.5	83.1	Medium

In the analysis presented in this paper, the MOVES model emission rates by STP operating mode bins across the assessed locations had identical inputs for model year (2012), vehicle type (transit bus), fuel type (diesel fuel), road type (urban restricted access), and age distribution (all 2012 vehicle fleet, or 0 years old). Geographic location, or county (with representative meteorology) varied across the twelve locations. For the six winter scenarios a January 6am hour was selected for modeling and a July 5pm hour for summer scenarios. Additionally, for each STP bin modeling run the average speed was specified based on the midpoint at each operating mode speed range. Thus, STP bins 11-16 used an average link speed of 20.9 km/h, and STP bins 21-30 used an average link speed of 60.4 km/h. STP bins 33-40, in the over 80.5 km/h speed range, used an average link speed of 80.5 km/h. Decelerating/braking STP bin 0 was assigned an average link speed of 20.9 km/h, given that it will go through the speed range of 40.2 km/h to 1.6 km/h while braking. Lastly, idle STP bin 1 used average link speed of 20.9 km/h since MOVES does not output a value for idle emissions when an average speed of zero is employed (Rome, 2012).

In the context of the MOVES model, a driving cycle pertains to a one-hertz vehicle speed-time trace that indicates typical operating conditions, showing acceleration, deceleration, and vehicle coasting (US EPA, 2009). Table 2 lists the seventeen heavy-duty transit bus driving cycles evaluated in the Calculator to measure the effects of different vehicle operating conditions on running emissions. Second-by-second speeds for the three freeway ramp cycles were approximated from data used to develop generic MOVES driving cycles (US EPA, 2009). The driving cycles account for the characteristic stops in transit bus operations and are representative of an extensive range of driving conditions from urban stop-and-go driving to express bus operations. The pollutants analyzed in this paper are carbon dioxide equivalent (CO_2e), a combination of various greenhouse gases that contributes to global warming, and oxides of nitrogen (NO_X) that are linked to ground-level ozone formation and are associated with adverse health effects.

Table 2. Heavy-duty transit bus driving cycles

Cycle	Cycle Name (Source)
HD-UDDS	Heavy-Duty Urban Dynamometer Driving Schedule (US EPA, ND)
OCTA	Orange County Transit Authority Cycle (SAE, 2009)
Manhattan	Manhattan Cycle (SAE, 2009)
NYBC	New York Bus Cycle (Carb, 2012)
NYCC	New York Composite Cycle (Diesel.Net, 2013)
WMATA	Washington Metropolitan Area Transit Authority Cycle (Carb, 2012)
Paris	Paris Cycle (Carb, 2012)
ETC-Urban	European Testing Cycle – Urban (NREL, 2012)
SF	San Francisco Cycle (UCD, 2012)
KCMC	King County Metro Cycle (Carb, 2012)
Beeline	Beeline Cycle (Carb, 2012)
CSHVC	City-Suburban Heavy-Vehicle Cycle (Carb, 2012)
CBD (SAE)	Central Business District Cycle (SAE, 2009)
WVU-5PEAK	West Virginia University 5-Peak Cycle (Diesel.Net, 2013)
On-Ramp	Freeway On-Ramp (US EPA, 2009)
Off-Ramp	Freeway Off-Ramp (US EPA, 2009)
Freeway to Freeway	Freeway to Freeway Transient Ramp (US EPA, 2009)

To create more tangible annual emissions estimates, indicative of an average transit agency, key parameters were selected in the Calculator as a representation of a transit agency the size of the Metropolitan Atlanta Rapid Transit Authority (MARTA):

- Urban Restricted Access roads—urban highways accessible by an on-ramp (to allow for ramp driving cycle analysis)
- Route length of approximately 16.1km
- Average Passenger Loading per Bus per Run of 40 passengers
- Number of Runs/Bus/Year as 3,650
- Number of Buses as 500 (NTD, 2012)

RESULTS AND DISCUSSIONS

To understand the MOVES model running exhaust emission rates, and subsequently the Calculator emissions estimates, Figure 1 illustrates the differences in MOVES produced diesel transit bus NO_X emission rates for all STP operating mode bins. The three gradual emission rate increases seen, for example from bin 21 to 30, are due to an increase in STP within a given speed range; as the speed range is raised, another distinct gradually increasing emission rates trend is seen with STP incrementally raising within that speed range. Idle operations from STP bin 1 generate 0.047 grams/second, the fourth highest NO_X emissions rates per STP bin. Figure 2 shows the MOVES generated diesel transit bus CO_2e emission rates for all STP operating mode bins. In this case idle STP bin 1 emission rates are nearly zero, but the influence of STP and speed ranges is seen again as the gradual increasing groups form; at higher speeds and higher engine load operations increasingly greater CO_2e emission rates are produced. Understanding of the different emission rates for each STP bin is integral to interpreting the Calculator estimated annual emissions across the seventeen evaluated heavy-duty bus driving cycles and selected locations.

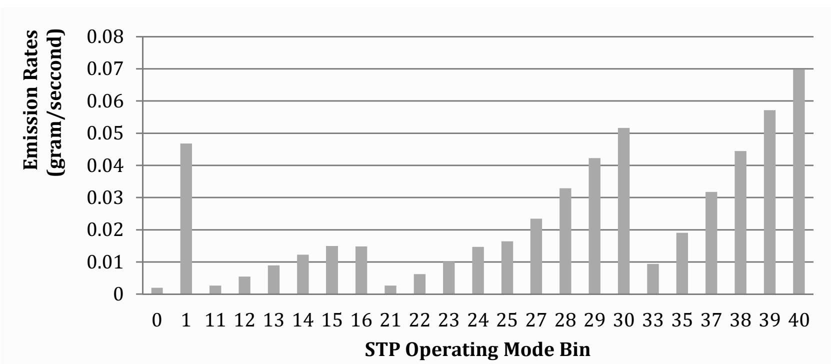

Figure 1. Atlanta MOVES NO_x emission rates by STP operating mode bin

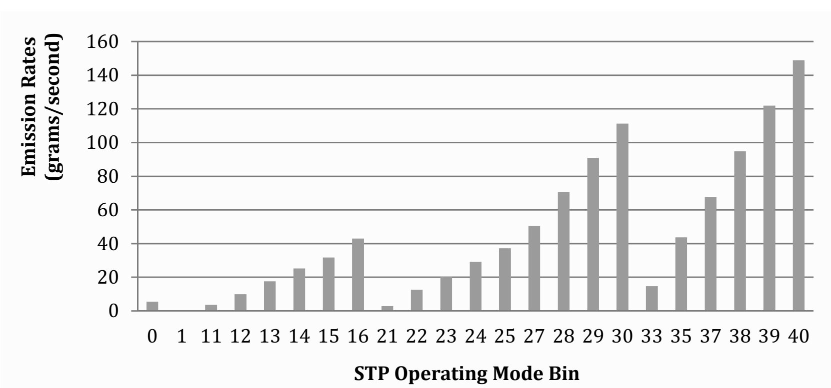

Figure 2. Atlanta MOVES CO_2e emission rates by STP operating mode bin

The EPA Heavy-Duty Urban Dynamometer Driving Schedule (HD-UDDS) is used to compare emissions for the twelve different locations and their representative meteorology. MOVES model generated NO_x and CO_2e running exhaust emission rates stored in the Calculator are used to estimate NO_x and CO_2e annual emissions. Figure 3 shows the HD-UDDS driving cycle annual NO_X emissions for all locations. MOVES model produced NO_X running emission rates are only sensitive for temperatures between 4.4º and 37.8º Celsius (Volpe, 2012), (Choi et al., 2010). Of the six locations within the temperature-sensitive range, with the exception of San Francisco, an inverse relationship is seen between temperature and emissions with Houston (33.0º C) having the lowest NO_X annual emissions and Miami (15.2º C) the highest. Moreover, locations outside of this temperature range (Seattle, Boston, Denver, Minneapolis, Dallas, and Phoenix) have the highest estimated NO_X annual emissions. In addition to temperature, NO_X emission rates are also inversely correlated with relative humidity (Volpe, 2012). The impact of humidity on NO_X emissions explains the differences in emissions across locations with similar temperatures, although the high NO_X emissions for San Francisco is most likely associated with the rough terrain of the city.

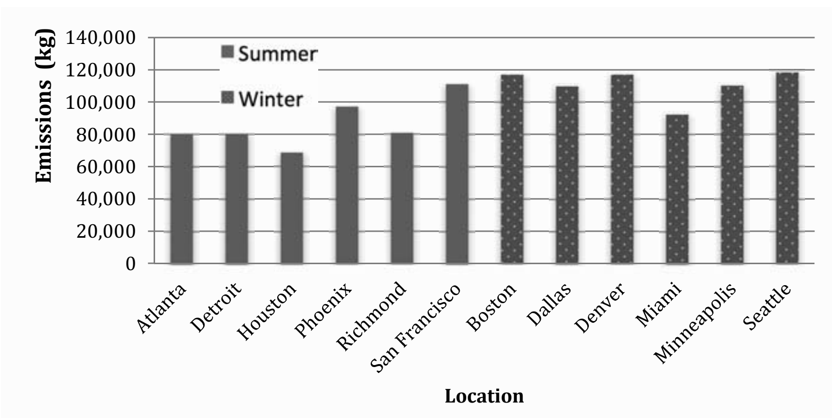

Figure 3. Annual HD-UDDS driving cycle NO_x emissions by location

Comparisons of CO_2e annual emissions are presented in Figure 4. Overall, lower CO_2e emissions are present across the winter months ranging from 35,282 metric tonnes in Dallas, Miami, and Minneapolis to 54,072 metric tonnes in Seattle. Lower CO_2e emissions in the winter months can be explained by the way MOVES applies the air conditioning adjustment when the heat index, an indicator that combines temperature and humidity, reaches a certain threshold (Brzezinski, 2011). The use of air conditioning in the summer months increases fuel consumption, which in turn increases GHG emissions. Again, the high emissions seen in the San Francisco scenario is likely linked to the rough terrain, despite its mild summer temperature.

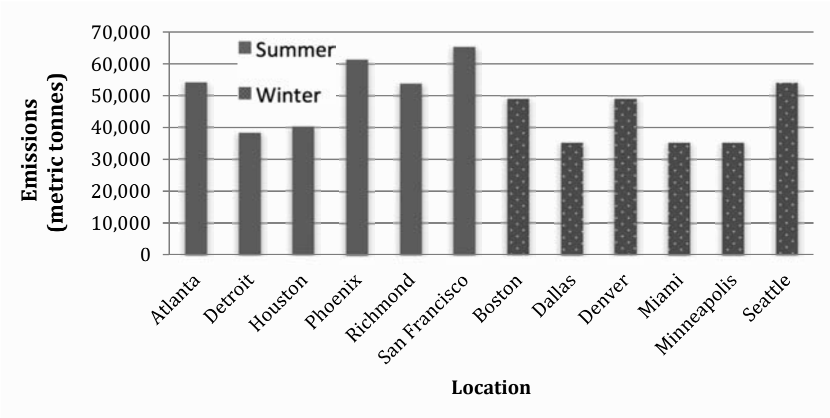

Figure 4. Annual HD-UDDS driving cycle CO_2e emissions by location

The MOVES model produced NO_X emission rates for the city of Atlanta were used to analyze the sensitivity of running exhaust emissions across the seventeen evaluated heavy-duty transit bus driving cycles. Figure 5 shows the Calculator estimated annual NO_X emissions across the seventeen evaluated driving cycles. The New York Bus Cycle (NYBC) has the highest annual NO_X emissions, at 621,174 kg, while the freeway to freeway ramp driving cycle has the lowest, at 30,779 kg.

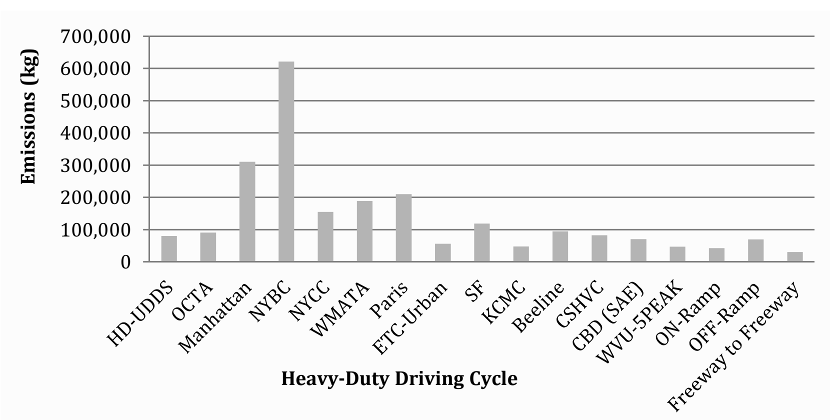

Figure 5. Annual Atlanta NO_X emissions by heavy-duty transit bus driving cycle

Comparably, Figure 6 displays the Calculator estimated annual CO_2e emissions for all seventeen assessed driving cycles. The NYBC driving cycle has the highest annual CO_2e emissions, at 106,556 metric tonnes while the West Virginia University 5-Peak Cycle (WVU-5PEAK) has the lowest, at 40,146 metric tonnes.

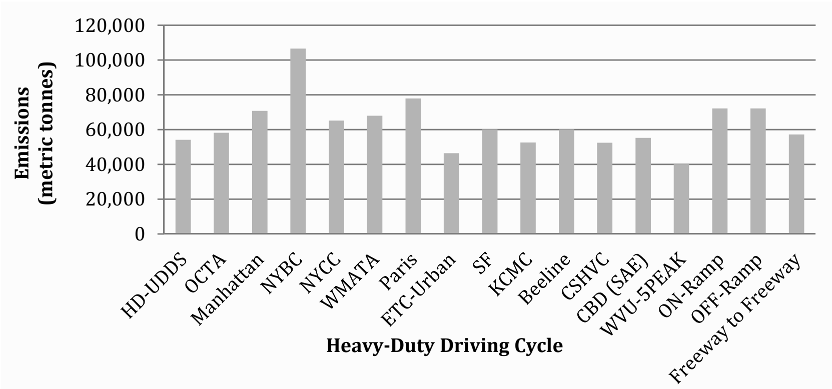

Figure 6. Annual Atlanta CO_2e emissions by heavy-duty transit bus driving cycle

Figure 7 shows the duration within each STP operating mode bin, for both the NYBC and the WVU-5PEAK driving cycles. NYBC cycle has over 400 seconds in the idle STP bin 1, and coupled with the MOVES generated emission rate for bin 1 seen in Figure 1, the high Calculator NYBC driving cycle NO_X annual emission estimates are justified. Additionally, the five driving cycles with the most time in the idle STP operating mode bin 1, as a percentage of the total cycle length, had the highest NO_X annual emission estimates (NYBC, Manhattan, Paris, WMATA, and NYCC, respectively). Similarly, the driving cycles in this analysis with the least time in the idle STP bin 1, such as the WVU-5PEAK and the freeway to freeway ramp driving cycles, produced lower NO_X annual emission estimates.

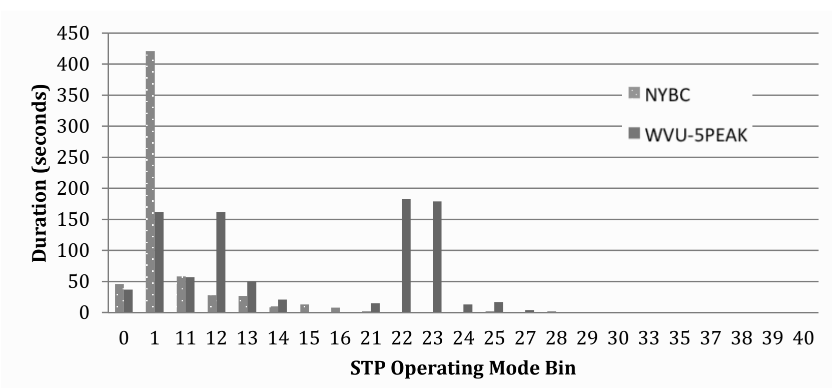

Figure 7. NYBC vs. WVU-5PEAK cycle STP operating mode bin distribution

Finally, the Calculator emissions estimates were compiled to compare the variations across the twelve locations, and the seventeen heavy-duty transit bus driving cycles. Figure 8 and Figure 9 show a 3D plot of all scenarios in the analysis, with annual NO_X and CO_2e running exhaust emissions displayed, respectively. Boston and Denver have the highest annual NO_X emissions under NYBC operating conditions with 952,893 kg, while the Houston freeway to freeway ramp driving cycle case has the lowest annual NO_X emissions with 25,795 kg. Notably, the greatest five annual NO_X emissions estimates fall outside of the temperature-sensitive range for the MOVES model generated NO_X running emission rates, which may explain the similarly high values. Long idle operating conditions linked with high MOVES NO_X emission rates from idle STP bin 1 contribute to greater NYBC estimated NO_X emissions.

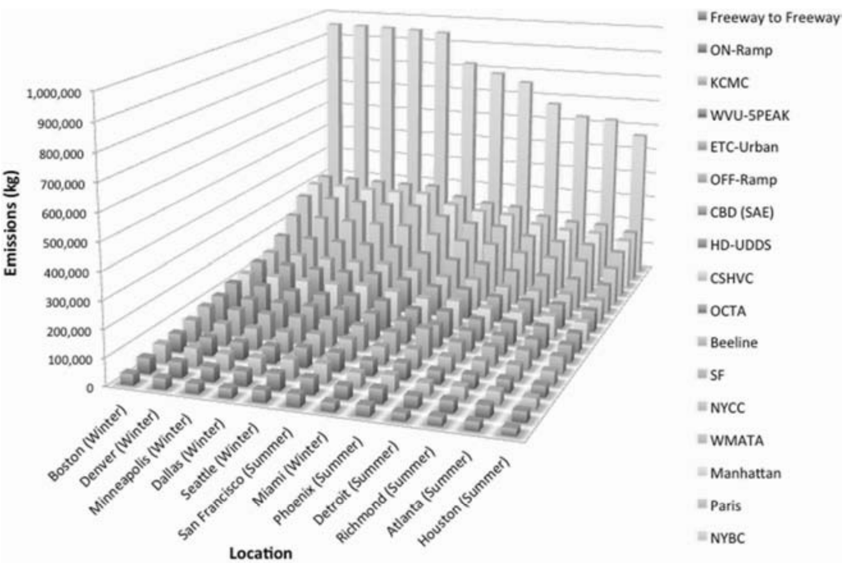

Figure 8. Annual NO_X emissions for all locations and heavy-duty driving cycles

The Calculator estimated annual CO_2e emissions, without the effect of high idle MOVES generated CO_2e emissions rates, are more similar in values across all scenarios as shown in Figure 9. Phoenix has the highest annual CO_2e emissions under NYBC operating conditions with 116,543 metric tonnes, and the Minneapolis WVU-5PEAK cycle has the least annual CO_2e emissions with 29,858 metric tonnes.

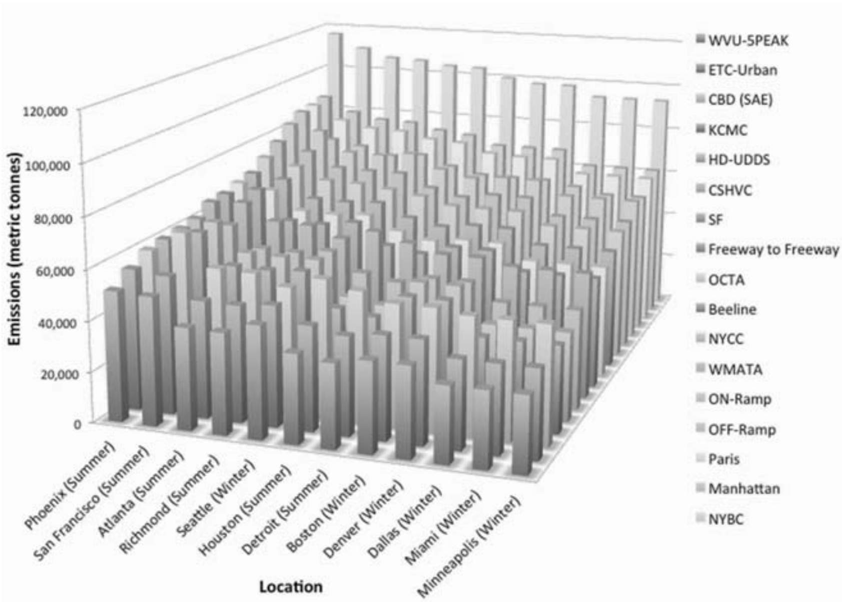

Figure 9. Annual CO_2e emissions for all locations and heavy-duty driving cycles

CONCLUSIONS

The analyses presented in this paper have shown that GHG and criteria pollutant emissions are sensitive to local and route conditions, including temperature, humidity, terrain, and drive cycle characteristics. Among the location scenarios and drive cycles included in this paper, the highest CO_2e emissions scenario (NYBC driving cycle in Phoenix summer) is almost four (4) times as much as the lowest CO_2e emissions scenario (WVU-5PEAK driving cycle in Minneapolis winter). For NO_X emissions the difference is even greater. The highest NO_X emissions scenario (NYBC driving cycle in Boston winter) produced almost 37 times as much NO_X emissions as seen in the scenario of the freeway to freeway ramp driving cycle in Houston summer. The sensitivity analyses have showcased the importance of considering local conditions when transit agencies engage in GHG analyses and planning. A GHG inventory analysis using the top-down fuel economy approach that adopts national average values would have completely overlooked the vast difference in emissions across varying locations and the accompanying meteorology. The ability to capture emissions differences associated with locations and routes will be especially important if a cap-and-trade program is in place and accurate accounting of GHG emissions is critical.

The results of this sensitivity analysis indicate the potential usefulness of the Calculator for use in evaluating emissions across driving cycles and environmental operation conditions in a comparative mode. The Calculator has the ability to derive CO_2e and criteria pollutant emissions that include computed upstream and on-road emission rates from varying heavy-duty transit bus driving cycles, allowing agencies to assess the combined emissions impact of fleet purchase and operation decisions. In the end, by creating performance estimates that relate GHG emissions reductions obtained to performance costs, the Calculator will assist public transit agencies, facilitating the choice of which alternative transit vehicle technologies to invest in.

Further research and testing of the Calculator and the accompanying MOVES2010b emission rate inputs is warranted and will continue to be conducted to understand and improve the output accuracy and overall performance.

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Integrating Travelers and Transit into Solutions for Congestion Relief

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ABSTRACT

Real-time highway and transit information, when presented in parallel, has the potential to influence travelers to make informed decision to choose transit when highway is congested to save time and to make of the transit trip less stressful and more productive or pleasurable. The mode shifts by commuters can potentially relieve traffic congestion, reduce fuel consumption and lower tailpipe emissions.

Under the sponsorship of USDOT and California Department of Transportation, California PATH at University of California at Berkeley developed and field tested Path2go -- a suite of both web-based and mobile-phone-based applications to assess if integrated multimodal real-time traveler information can enable travelers to make choice decisions. Evaluation of data collected through field testing showed that the Path2go application performed well with regard to its capability to integrate real-time, multimodal information, the accuracy and reliability of the information, its usefulness in helping users to reduce waiting time and overall travel time, and its effectiveness in encouraging travelers to consider transit as a more viable choice.

1. INTRODUCTION

Despite the substantial improvements made through infrastructure improvements and various congestion mitigation efforts, congestion on highways in metropolitan areas persists, costing travel time, fuel and money, hindering economic development, and negatively impacting the environment. On-going highway improvements and traffic management through deployment of intelligent transportation systems (ITS) technologies have improved services on existing roads. However, congestion persists due to the fact that traffic demand in almost all metropolitan areas approaches or exceeds the available capacities of the highway systems. An alternative to continuously building highway capacity is to manage travel demand to reduce congestions.

While one may argue whether 60% of highway congestion, mostly during peak periods, is non-recurrent, a significant portion of incident-caused congestion is attributed to the fact that demand exceeds capacity. Mode shift from single occupancy vehicles to transit buses will reduce the total number of vehicles on the road, significantly reducing fuel consumption and emissions. Figure 1 displays the Freeway performance (PeMs) data for U.S. Interstate I-110, depicting that freeway travel speed varies dramatically between 10 mph and 70 mph when traffic demand is more than 3000 vehicles/hour across all lanes on I-110. When traffic demand is below 3000 vehicles/hour, the travel speed is maintained stable at the free flow speed of 65mph. The analysis of the I-101 corridor shows that if some drivers are motivated to use transit during the peak hours or to travel at off peak periods to reduce the total number of vehicles on I-101 to close to 3000, it is highly possible that the large variation of the travel speed will be eliminated and the freeway can be kept at a free flow speed of 65 mph, resulting in congestion relief on the highways and reduction of trip time and costs for all travelers. The congestion relief also provides fuel savings and emission reductions for the vehicles remaining on the highways.

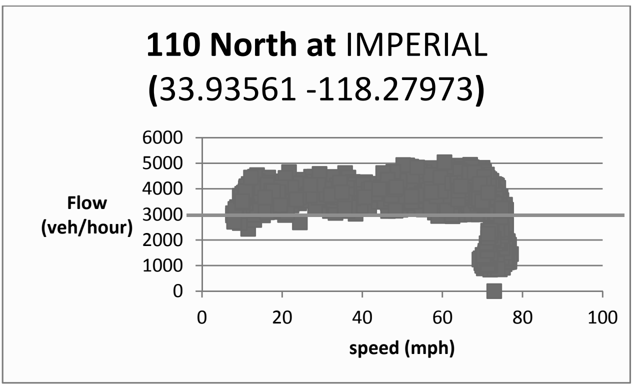

Figure 1 Speed vs. Flow Relationship Diagram US710N at Washington and 110N at Imperial in May 2011

Demand management and smart land use have been viewed as foundations for transportation management. Use various tools to encourage people to change travel behavior and to collaborate with the transportation systems can be are cost-saving alternatives to building ever-increasing highway and public transit capacity. However, the existing demand management tools, including traveler information, road pricing, incentives to encourage mode shifts and carpooling have not been widely used in use in the United States for various reasons. Their effects on congestion relief have not been very well understood. The paper provides a summary of a field study for assessing the effectiveness of real-time multimodal information system.

2. TRANSIT'S ROLE IN CONGESTION RELIEF

The ability to change travel behavior depends as well upon the extent to which alternative choices are made available by the transportation network itself. The general perception is that the public transportation system in the United States has not been effectively utilized. APTA data show that only about 1-2% of the travelers in the US use public transit as a mode of choice for their commute. However, transit users are concentrated in urban areas where congestion most frequently occurs, particularly in regions that have well connected rail transit services. Data, as summarized in Table 1, shows that rail transit riders account for 20% to 40% travelers along the major corridors in the San Francisco Bay Area. Transit has become more attractive an option for travelers as a result of gasoline price increases since 2008. APTA reported a record 4.36 percent ridership increase overall for transit systems and a 12% increase for commuter and light rail systems in 2008 compared with a year earlier. Data from the subsequent years show that after gas prices moderated, travelers who changed to transit tended to stay with transit. APTA data also show, through the recent gas price increase event, that travelers can be motivated to change their travel behavior when travel options are available and viable, and that once travelers get used to the alternative travel mode, they often continue to use such a mode.

Table 1 Statistics of travelers along major corridors in the San Francisco Bay Area

	24ERock	24WRock	80EUniv	80WUni	880NFru	880SFru	101NSFO	101SSFO
Vehicle volume per direction	78,531	72,633	38,541	36,277	101,738	104,582	125,304	105,291
Total vehicle volume	151,164		74,818		206,320		230,595	
BART Riders	76,797		52,103		110,298		113,895	
Caltrain Riders							36,778	
Total travelers	227,961		126,921		316,618		381,268	
Transit riders/total travelers	34%		41%		35%		40%	

Analysis through our study shows that the following reasons have been the major causes for travelers not to choose transit: (1) travelers tended to think transit is slow and transit station parking lots are full, (2) for many travelers, taking transit requires one or more transfers between modes, (3) travelers generally do not know their travel alternatives, and (4) there have been inadequate motivations triggering them to change mode. The challenge lies in what 'triggers' can motivate a large enough traveler population to result in substantial reduction of traffic congestion. Demand management tools, including real-time multimodal traveler information, are one means by which to encourage travelers to move from single occupancy vehicles to transit or to travel during non-peak hours, thereby reducing or eliminating congestion levels.

3. USE MULTIMODAL REAL-TIME TRAVELER INFORMATION FOR CONGESTION RELIEF

Commuters account for a large percentage of travelers in metropolitan regions, particularly during congested peak periods. Reaching the congestion relief goal requires informed participation of a large number of travelers. While commuters' chief interest is to get to their destination quickly, many of them potentially have other interests, including fuel/cost savings, comfort and convenience, efficient use of travel time for productivity, improved safety or reduced chance of accidents, and more recently, emission reduction for a sustainable environment. Mode shift by commuters can potentially relieve traffic congestion, reduce fuel consumption, lower tailpipe emission, as well as enable travelers to make of the trip less stressful and more productive or pleasurable. Use of real-time traveler information can be an effective means to empower travelers to change their travel behavior for achieving demand reduction.

A real-time information system will be most effective if it is tailored to the travelers' interests. Previous studies show that the effectiveness of real-time traveler information on changing travelers' behavior relies on a number of factors, including whether the information has adequate content for travelers to make well-informed decisions, the reliability of the information, and how the information is presented to the travelers. An ideal system minimizes effort for the users in acquiring information on mode choice options and is able to expose the user to information on such options even if they had not intended to consider or review a mode choice decision when accessing the service. Integrated multimodal information systems that provide travelers with information about more than one mode of travel may be more ideal to travelers than presenting traffic and transit information independently. Properly presented integrated multi-modal information with high accuracy and proper level of detail and visualization could help educate drivers to overcome the barriers to modal change.

There have been significant efforts and several on-going programs to encourage travelers to change their travel behavior. '511' traveler information systems provide real-time information helping people to avoid congestion, but most of these system use separate information interfaces for traffic and transit information and trip planning. The lack of real-time multi-model information has prevented travelers from making mode choice decisions based on true comparisons of the travel time between freeway travel and transit. Moreover, the existing traveler information systems typically do not have ability to analyze how people have used such information for their trip decisions and the effect of such information [Kenyon, 2003].

Most of the cited studies on the impact of real-time information are based on an analysis conducted through simulator studies and opinion survey results using "conceived preferences," rather than the outcomes of actual choices. Although the social psychology literature indicates there is a strong link between stated intentions and actual behavior, most of the survey results may not fully represent actual choices nor be consistent with verifiable data on travel patterns. For example, in one survey study, people who indicated interest in carpooling were sent carpool matching lists to form carpools but half of them indicated in a follow-up survey that they really were not interested in carpooling (Dueker, 1977). The stated preferences for carpooling by solo drivers might not really reflect the actual behavioral change that will take place (Baldassare,
1998). There is still a large knowledge gap between the analysis of real-world behavior and associated changes influenced by real-time information and the subsequent impact on traffic congestion.

4. DEVELOP AND FIELD OPERATIONAL TESTING OF PATH2GO MULTIMODAL REAL-TIME TRAVELER INFORMATION SYSTEM

Researchers have hypothesized that travelers with travel options will be benefited from integrated real-time transit arrival time, parking availability information and freeway/arterial travel time, with which travelers will be able to determine the quickest and convenient way of travel, and are less likely to miss a train or get to the train station without being able to find a parking space. In order to assess how real-time information may affect choice decisions by travelers, California PATH developed a suite of applications named Path2go based on real-time highway, transit and parking information (www.networkedtraveler.org). This study was conducted under the sponsorship of US Department of Transportation Research and Innovative Technology Administration (RITA) and California Department of Transportation, in partnership with the Metropolitan Transportation Commission, Santa Clara Valley Transit Agency, San Mateo Transit Authority and private partners including Navteq, ParkingCarma, and SpeedInfo.

US101 corridor in the San Francisco Bay Area has been selected as the test site. The US101 has been one of the most congested highways in California. Parallel to US 101, the corridor is connected by a major arterial highway El Camino Real (also known as State Route 82) and a commuter rail Caltrain and the Bay Area Rapid Transit system (BART). A number of bus routes are operated by San Mateo Transit Authority (SamTrans), San Francisco Muni (Muni) and Valley Transportation Agencies (VTA) in the vicinity of the corridor. The parallel transit systems have excessive capacities during peak hours, offering alternative commute choices for travelers.

The US101 corridor is well instrumented to provide real-time freeway performance data. In order to provide real-time multimodal information, PATH made institutional arrangements and developed interfaces to receive real-time data from Muni, Samtrans and BART. PATH also instrumented all Caltrain trains and selected VTA buses with AVL for real-time data. The field test corridor Figure 2 shows the system architecture of Path2go. The data feed which includes data inputs, Path2go system and freeway changeable message sign systems.

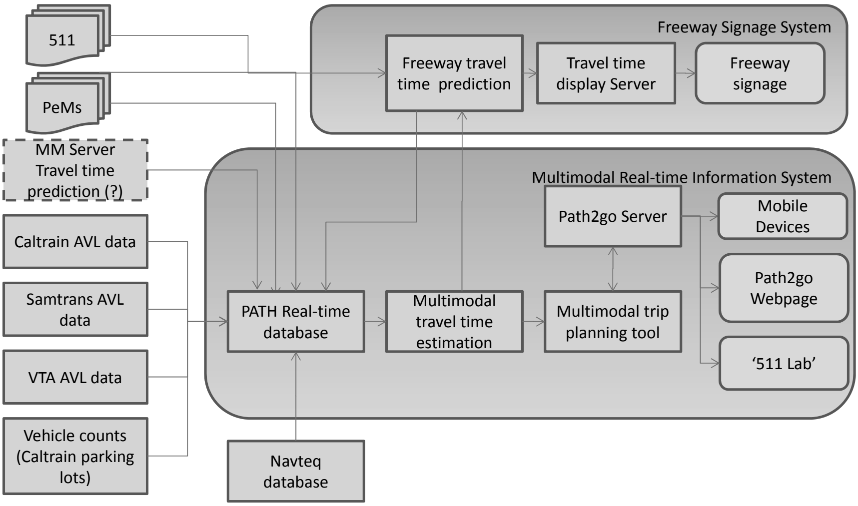

Figure 2 System architecture of Path2go

A dynamic multi-modal transit and traffic network is implemented as part of the trip planning engine. A dedicated thread on the server updates the network using real-time transit arrival information and real-time traffic data periodically [Li, 2012]. Multi-source time-dependent shortest path algorithms for the transit-only or park-and-ride mode based on users' expected departure time (via a forward algorithm) or arrival time (via a backward algorithm) has been designed to achieve trip planning goals with acceptable computational time. Path2go is designed as a server-based system, making it possible to evaluate the potential influence of real-time multimodal traveler information on mode choice decisions.

Path2go is one of the first attempts to integrate a suite of both web-based and mobile-phone-based applications to provide travelers with integrated multimodal real-time information. Substantial efforts are devoted to develop the Path2go applications, user interfaces as well as to ensure the reliability of real-time information, which is a significant factor to influence travelers' pre-trip departure time and route-switching decisions, as well as the en-route path changing decisions.

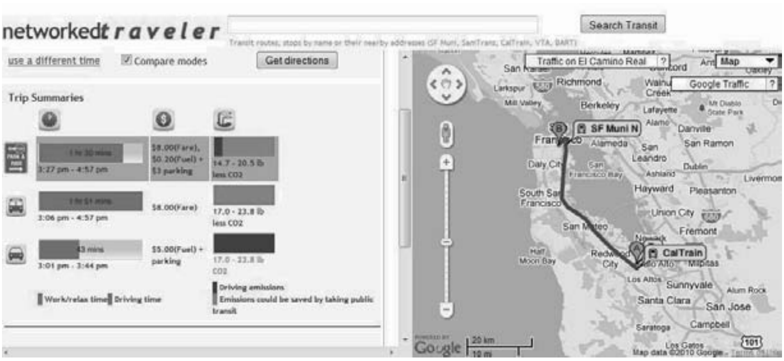

Figure 3 Integrated multimodal traveler information user interface.

The web-based trip planner, as shown in Figure 3, enables users to plan and compare trip options involving a combination of driving and/or taking transit. Users can also compare trips using different modes of travel based on real-time travel time, cost and the carbon footprint. Once a trip has been planned, it can then be sent to user's smart phone (iPhone, Android or Windows Mobile platforms) to receive real-time updates on the bus/train arrival times and arrival audio alerts before bus/train arrives at a station. In addition to receiving information about the planned trips made using the web-based trip planner, the mobile phone clients can also be used to plan for transit trips, obtain real-time status updates and provide alerts during a trip. Path2go also displays the real-time highway and transit travel time and parking availability on freeway overhead Changeable Message Signs (CMS) before a major transit station along 101 during the rush hour. This information can potentially inform travelers their transit options when highway congestion occurs.

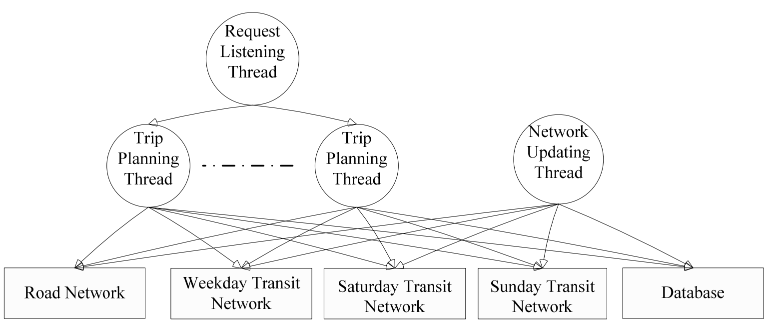

Figure 4. The architecture of the trip planning server

5. RESULTS FROM FIELD OPERATIONAL TESTS

Field testing of Path2Go was conducted between August and November, 2010, involving volunteer commuters along US101 corridor who have access to PATH2Go web-based trip planning tools and smart phone applications. Over 750+ registered mobile phone users and 1000+ web users were recruited. Trip planning and execution data were collected and analyzed to assess the effectiveness of real-time multimodal information on travel behavior. In addition to the data collected, users are invited to take a detailed survey at the end of the field testing. Data were analyzed by an independent evaluator to evaluate the effectiveness of the integrated real-time multi-modal information and if it likely encourages travelers to consider transit as a viable option [Jasper, 2011].

Users of the PATH2Go applications were asked to provide feedback to the applications. 244 surveys regarding the demographic characteristics and usages were received. In addition, 51 web surveys and 31 cell phone surveys were also collected. The survey results indicate that, the commute trip distance is diversified, with the median trip distance of slightly less than 20 miles. Most of the trips undertaken by the respondents are below 45 minutes. More than 40% of the respondents reported using 2 or more modes for commuting. In addition, 60% of the survey takers considered transit as a mode of choice, followed closely by driving at about 55%. Carpooling and other mode choices remain unfavorable to majority of respondents. When asked about the number of traffic information sources utilized, about one quarter of the respondents indicated that they do not seek such information, while 43% use one information source only. 511 services are considered the most popular type of information source, used by over 40% of the respondents, followed by Google with 30% usage rate.

Table 2 Survey results from the independent evaluation report

Question	agree/strongly agree	disagree/strongly disagree
Application provided valuable information	56%	14%
Ability of access information for multiple agencies is useful	65%	10%
Information is accurate	40%	12%
Information of path2go makes me feel more confident about using public transit	40%	20%

Through the web surveys, two-thirds of the respondents considered the PATH2Go applications were satisfactory, while 27.5% has no opinion and 6% gave the applications poor ratings. In general, well above half of the respondents indicated that the information provided was useful, accurate and helpful for them to reduce waiting time. They stated that and the information had influenced them to consider transit as a more viable choice. Users also inputted comments for possible technical and service improvements such as to load/save favorite maps and incorporate information for AC Transit. The cell phone survey received positive overall ratings, with more than half of the users finding the application useful. However, the high dissatisfaction rate shows that there is still space for improvements, particularly the user interface

Independent evaluation results are summarized in Table 2. To answer the key question regarding how Path2go include mode choice decisions, 32% respondents indicate that Path2go makes them more likely to choose an alternative mode while 38% not. More analysis and evaluation of the FOT data can be found in the independent evaluator's report.

6. FUTURE IMPROVEMENTS

PATH is continuing the development of Path2go based on the experience of the FOT conducted along I-101 corridor to improve the functionalities and user interface design for better usability. Both the web interface and mobile interface will be redesigned to make the user interface easier to use, more intuitive and presents the information in a more organized way.

The field test of Path2go involves about 1000 travelers to evaluate whether travelers would make mode shift decisions using a specific real-time multimodal information interface. Because of the limited scope of the field test, the influence of traveler information on decisions regarding the time at which to travel was not measured and the impact on congestion relief was not measurable. Caltrans and PATH plan to conduct larger scale field operational test in the LA region. A thorough field evaluation will be conducted to collect objective and subjective data.

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Experimental Analysis in VISSIM of Single-Lane Roundabout Slip Lane Under Varying Bus Traffic Percentages

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ABSTRACT

Performance of single-lane roundabouts with an adjacent slip lane for right turns is evaluated under a yield exit control scenario and varying bus traffic percentages. VISSIM microsimulation assessment considers experimental origin-destination (O-D) balanced flow scenarios (total traffic flow into and out of every roundabout approach is the same) with four different right-turning bus traffic percentages (low, moderate, high, and all compared to no buses). Simulated slip lane right-turning traffic volumes range from 50 to 500 vehicles per hour. Results indicate that average delay of a roundabout with slip lane has a non-linear relationship with slip lane volumes and is sensitive to changing bus traffic percentages, before oversaturation occurs. As expected, results indicate that a yield slip lane exit type significantly reduces total roundabout average delay, compared to having no slip lane. Finally, results suggest theoretical threshold values at which the use of a slip lane is demonstrably beneficial as bus traffic percentages change.

Author keywords: Roundabout**,** slip lane, bus traffic percentages, VISSIM.

INTRODUCTION

Roundabouts can be used as an alternate intersection design to facilitate major traffic turning movements and to enhance operational and safety performance. A slip lane, a separate lane that facilitates right-turning traffic flow, reduces approach delay by allowing right-turning movements to bypass the roundabout, thereby reducing vehicle conflicts. Though roundabouts are an increasingly common form of intersection control in the U.S., research has yet to quantify slip lane contributions to operational and safety improvements when slip lanes are installed.

NCHRP Reports 572 (2007) and 672 (2010) define two types of slip lane: a non-yield slip lane, merging with the roundabout exit leg and forming a new acceleration (free-flow) lane adjacent to exiting traffic; and a yield slip lane, terminating at a sharp angle with the roundabout exit approach so that right-turning traffic is yielding.

Operational performance of roundabouts, measured as roundabout capacity, typically is based on one of three capacity methods: gap acceptance; empirical regression; or a

hybrid of gap and empirical methods. TRB (2000) and (NCHRP 2007; 2010) provided roundabout capacity models as a function of the circulating flow in the roundabout, follow-up headway, and critical gap. They estimated the capacity of a roundabout's approach (entry lanes) via input parameters such as circulating conflicting traffic volume, follow-up time, and critical gap.
VISSIM, from Germany, is "a microscopic, time-step and behavior-based simulation model" (PTV 2007). Commonly used to simulate traffic operations at roundabouts, it is based on major traffic theories of the car following and lane change logic. Its traffic simulation emphasizes random distributions of driver behavioral attributes such as aggressiveness and gap acceptance, and other parameters such as vehicle arrivals, vehicle speeds, vehicle type, and others (PTV 2007). VISSIM uses inputs such as lane assignments and geometries, intersection traffic turning movement volumes, vehicle travel speeds, percentages of vehicles by type (car, bus, and truck), public transport vehicle line route alignment, and signal timing.

Several studies have used VISSIM to evaluate roundabout operational performance by changing geometric and behavior features. Trueblood and Dale (2003) described key VISSIM features for effective simulation of roundabouts, including link and connector, routing decisions, reduced speed zone, and priority rules.

Using VISSIM to simulate the Bus Lane with Intermittent Priority (BLIMP), FTA (2009) completed a preliminary study to determine potential impacts of a new and innovative transit priority treatment along a corridor in Eugene, Oregon. The simulation utilized dynamic lane assignment to designate an exclusive bus lane on a temporary, bus-actuated basis. VISSIM results showed that implementation of the BLIMP concept would improve travel time, while having minimal impact (reduction) on overall intersection delay.

Jing-Quan et al. (2009) studied Bus Rapid Transit (BRT) systems with dedicated lanes, using VISSIM to examine impacts of the BRT bus on other traffic and performance of the speed control. Their simulation result showed that the speed control effectively handles the delay in the intersection and the other traffic is rarely affected by the speed control.

Using VISSIM to study a slip lane for a single-lane roundabout, Al-Ghandour et al. (2011) confirmed that average delay and circulating conflict volumes are related exponentially to slip lane volumes before roundabout oversaturation. Also, results showed that before oversaturation occurred, overall roundabout average delay was reduced 22% with use of a yield slip lane exit type, without bus traffic.

No research was found that evaluated roundabout operational performances for a single-lane roundabout with bus traffic with and without a slip lane. This paper, an extension to the Al-Ghandour et al. (2011) study, tests two hypotheses:

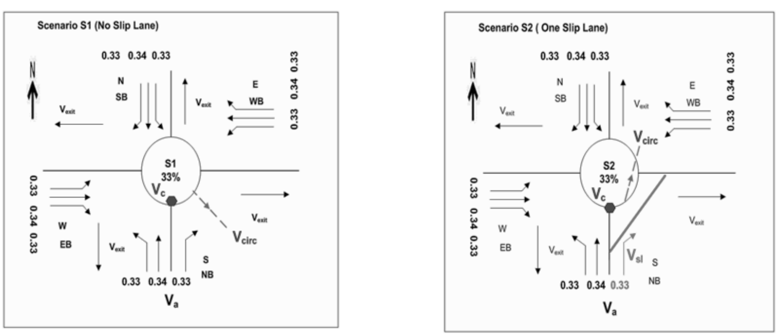
1. *Hypothesis H1*: Bus lane managed by slip lane yield exit type should reduce average delay in a single-lane roundabout, thereby improving its operational

performance (its capacity as indicated by average delay), compared to a base single-lane roundabout without a slip lane.

2. *Hypothesis H2*: Bus lane managed by slip lane theoretical threshold capacity volumes increase with increased roundabout right-turn traffic volumes. A threshold value is the limit in volumes at which the roundabout operates with a capacity as transition to level of service F (traffic congestion is the result of more traffic flow demand than capacity).

METHODOLOGY

In this paper, a slip lane-based experimental simulation model is used to determine the capacity of each approach and of the entire roundabout (including slip lanes). For a single-lane roundabout with a slip lane, experimental traffic percentage turning volume distributions (scenarios) were studied under the assumption that total traffic flow into and out of each roundabout approach is the same. Scenarios S1 and S2, illustrated in Figure 1, were initialized, analyzed, and then controlled through several iterations to keep balanced volumes. A slip lane was assumed to be placed at the northbound (NB) entry to the roundabout. Three experiment design variables were tested across the scenarios: 1) a yield slip lane exit type control; 2) slip lane right-turning traffic volume (in increments of 50 vehicles per hour and ranging from 50 to 500 vehicles per hour—representing low, moderate, and high volumes); and 3) four different bus traffic percentages (low: 5%, moderate: 25%, and high: 45%) compared to no buses (0%). These bus traffic percentages are labeled as: Bus5, Bus25, Bus45, and Bus0, respectively.



V_a: Approach volumes per approach, vehicles per hour. V_c: Conflicting volumes for northbound entry (NB), vehicles per hour. V_{cir}: Circulating volumes for northbound entry (NB), vehicles per hour. V_{sl}: Slip lane volumes as dominant right turn, vehicles per hour.

Figure 1. Experimental O-D Flow Pattern Scenarios (S1-S2).

It is assumed that roundabout entry and exit flow volumes for each approach are the same (balanced), although the dominant right-turning traffic percentages in the slip lane are different (33%). It is also assumed that all right-turning traffic (vehicles and buses per the percentages) will enter the slip lane rather than the roundabout and there are no bus stops off the slip lane or roundabout lanes. All default values from VISSIM were kept such as geometry, transit, and priority rules.

Volume distributions for the roundabout, developed from the traffic percentage distribution matrices, are summarized (Table 1) in a sample of three volumes: 50, 250, and 500 vehicles per hour. Volumes for each roundabout approach (V_a) are the same as for exit approach (V_{exit}) volumes, based on the assumption of experimental balanced roundabout scenarios (Figure 1). For example, the dominant right turn flow percentage (33%), sustains more traffic volume on both approach entry (V_a) and exit approaches (V_{exit}) and circulating flow (V_{cir}). At a slip lane (right-turn) volume V_{sl}=500 vehicles per hour for scenario S1, a 33% dominant level shows a volume at each approach (V_a) of 1,515 vehicles per hour with a bus volume of 225 buses per hour (italicized and highlighted in yellow, Table 1). The conflicting circulating volumes (V_c) for scenario S1 (1,515 vehicles per hour) also have same volumes at each approach (V_a) due to balanced O-D.

All traffic volume distribution scenarios (S1and S2) for different bus traffic percentages were coded into VISSIM, as shown in Figure 2, to evaluate the performance of a slip lane in terms of average delay and VISSIM sensitivity. The total minimum number of VISSIM runs was 20 (1-hour) based on statistical equation to be met with a 95% confidence interval and acceptable error. In total, 80 scenarios were modeled: 1 traffic O-D (33%) x 10 traffic volumes (50 to 500 vehicles/hour) x 2 slip lane types (yield and no slip lane) x 4 right-turning bus traffic percentages (0, 5, 25, and 45). For each simulation scenario, 20 VISSIM runs, executed using different random number seeds, resulted in a total of 1,600 simulations. Average roundabout delay (in seconds) for all vehicles entering the roundabout is used in this study as the Measure of Effectiveness (MOE) of the roundabout.

Table 1. Total Approach, Conflicting, and Bus Volumes.

V_{sl}: Slip Lane Volume, Right-Turn Volume (vehicles per hour) at NB Approach	Total Approach and Conflicting Volumes (vehicles per hour)		Scenarios Buses per Hour			
			Bus0 (0%) No Buses	Bus5 (5%) Buses	Bus25 (25%) Buses	Bus45 (45%) Buses
V_{sl} =50 (Low)	V_a V_c	150 (150)	50	3	13	23
V_{sl} =250 (Moderate)	V_a V_c	757 (757)	250	13	63	113
V_{sl} =500 (High)	V_a V_c	1,515 (1,515)	500	25	125	*225*

V_a: Approach volumes per approach, vehicles per hour. V_c: Conflicting volumes for northbound entry (NB), vehicles per hour. V_{sl}: Slip lane volumes as dominant right turn, vehicles per hour.

ANALYSIS AND RESULTS

As more traffic is diverted outside the roundabout on the slip lane (right-turn movement), the slip lane reduces more of the roundabout conflicting circulating volumes (V_c) and more of the conflicting off-slip lane approach volumes.

a) No Slip Lane **b) Yield Slip Lane**

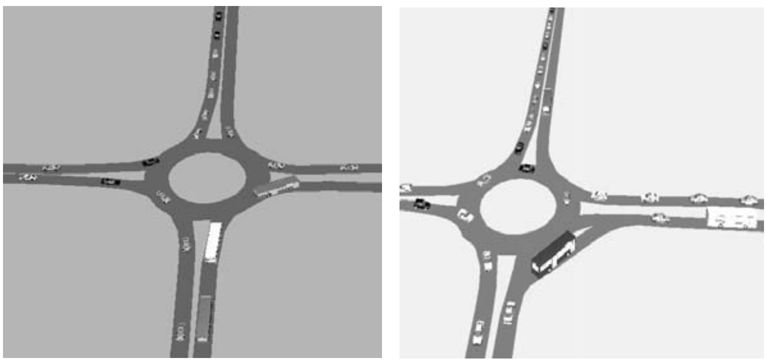


Figure 2. VISSIM Snapshots with Bus Managed Slip Lane, Scenarios S1-S2.

Average Roundabout Delay

For all bus traffic percentages, a yield exit type has less delay than a no slip lane exit type. Thus, reduction of delay via the use of a yield slip lane is shown to be greater than having no slip lane, under varying bus traffic percentages. Table 2 provides a sample of results from VISSIM MOE: average vehicle delay is measured in seconds (bold) for all vehicles (mixed) in the roundabout (RBT) for scenarios S1 and S2 with four bus traffic percentages (Bus0, Bus5, Bus25, and Bus45) as (no buses: 0%, low: 5%, moderate: 25%, and high: 45%), respectively. For example, scenario S2 at moderate traffic volumes (V_{sl} =250 vehicles per hour) and no buses (Bus0) shows a significant reduction (improvement) of average delay: from 41 seconds per vehicle (no slip lane) to about 34.8 seconds per vehicle—a 15% reduction (calculated as -15.12 %=((41-34.8)/41)). As bus traffic volume percentages increase from Bus0 to Bus45, delay increases (i.e., delay reduction percentages decrease) because the roundabout traffic becomes oversaturated. For example, in scenario S2 at moderate traffic volumes (V_{sl} =250 vehicles per hour) and (Bus45), there is less significant average delay reduction (-3%, calculated as -2.94 %=((46.3-47.7)/47.7)).

For each scenario, standard deviation and standard of errors also are shown (Table 2) for the average delays that tested statistically significant using the 95% confidence interval (alpha 0.05). For example, in scenario (S2) for bus traffic (Bus45) and with high traffic volumes V_{sl} = 500 vehicles per hour, the standard deviation for MOE delay is 16.0 sec/vehicle with standard errors of 3.57 for the mean delay 49.7 sec/vehicle (italicized and highlighted in yellow, Table 2).

Figure 3 shows samples for all bus traffic percentages of a comparison between roundabout average delays for no slip lane and a yield slip lane exit type. At V_{sl} = 300 vehicles per hour, with no slip lane and no buses (Bus0), average delay for a single-lane roundabout is 45.4 seconds per vehicle; and 41.2 seconds per vehicle with a yield slip lane. For no slip lane and 45% bus traffic percentages (Bus45), the roundabout average delay is 49.3 seconds per vehicle, and for a yield slip lane, 48.9 seconds per vehicle. As slip lane (right-turning) traffic volumes (V_{sl}) increase, conflicting circulating volumes (V_c) decrease and average delay also decreases, in an exponential relationship. Significant changes in entry flow (V_a) and circulating flow (V_c) cause a higher impact on the total average delay within a roundabout with a slip lane and under varying bus traffic percentages.

Table 2. Summary of VISSIM Average Delays.

Slip Lane Exit Type	**V_{sl}: Slip Lane Volume, Right-Turn Volume (vehicles per hour) at NB Approach**	**Average Delay (sec/vehicle)**				
		Bus Traffic Percentages				
		Statistical Results	**Bus0 (0%) No Buses**	**Bus5 (5%) Buses**	**Bus25 (25%) Buses**	**Bus45 (45%) Buses**
			RBT	**RBT**	**RBT**	**RBT**
S2 Yield	50 (Low)	**Average**	**0.9**	**1.2**	**1.0**	**1.1**
		Std. Dev. (StErr)	*1.2 (0.26)*	*1.8 (0.40)*	*1.9 (0.42)*	*1.9 (0.42)*
	250 (Med)	Average	**34.8**	**40.2**	**46.2**	**46.3**
		Std. Dev. (StErr)	*21 (4.69)*	*18.9 (4.23)*	*17.6 (3.93)*	*18.3 (4.09)*
	500 (High)	**Average**	**44**	**45.2**	**49**	***49.7***
		Std. Dev. (StErr)	*16.9 (3.77)*	*15.9 (3.56)*	*15.6 (3.48)*	*16.0* ***(3.57)***
S1 No Slip	50 (Low)	Average	**1.0**	**1.4**	**1.3**	**1.4**
		Std. Dev. (StErr)	*1.2 (0.26)*	*2.3 (0.51)*	*2.2 (0.49)*	*2.3 (0.51)*
	250 (Med)	Average	**41**	**40.7**	**47.4**	**47.7**
		Std. Dev. (StErr)	*17.3 (3.86)*	*19.6 (4.38)*	*24.1 (5.38)*	*25.2 (5.63)*
	500 (High)	**Average**	**46.3**	**47.1**	**50.2**	**50.8**
		Std. Dev. (StErr)	*13.8 (3.08)*	*15.3 (3.42)*	*18.4 (4.11)*	*19.7 (4.40)*

V_{sl}: Slip lane volumes as dominant right turn, vehicles per hour. RBT: roundabout. SL: Slip lane. Yield: Slip lane with a yield exit type. No Slip: No slip lane (base). *StErr: Standard of Error: (Std. Dev.)* Standard deviation divided by square root of number of runs.

The highest roundabout average delay, observed in scenario S1 (no slip lane with 45% bus traffic percentages (Bus45)), was a result of the combined highest approach volumes (V_a), highest total roundabout volumes, and highest conflicting circulating flow (V_c). The lowest roundabout average delay, observed in scenario S2 (a yield slip lane with no buses (Bus0)), was a result of the combined lowest approach volumes (V_a), lowest total roundabout volumes, and lowest conflicting circulating flow (V_c). Therefore, under different scenarios, slip lane performance is most effective under a higher right-turning traffic pattern distribution. Slight changes between approach entry lane flow (V_a) and circulating flow (V_c) cause less impact (reduction) on total average delay within a roundabout with a slip lane when bus traffic volumes increase.

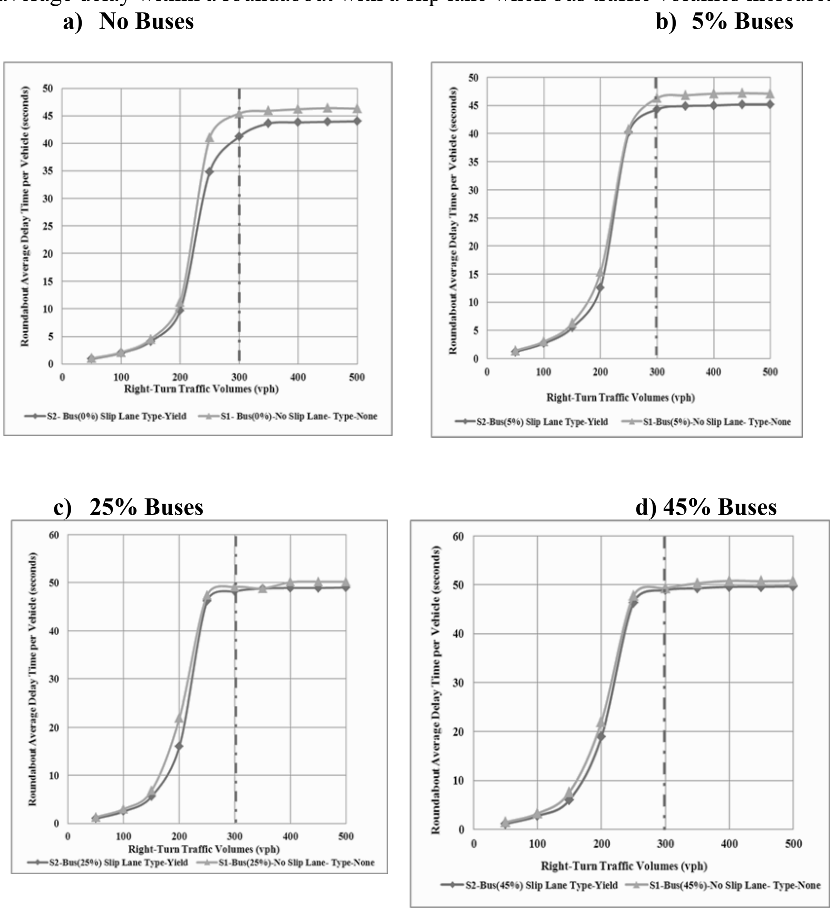


Figure 3. VISSIM Roundabout Average Delay for Scenarios S1-S2.

Threshold Capacity Values

Slip lane theoretical threshold volumes were determined when the roundabout operates with a volume/capacity ratio greater than 1.00 as transition to Level of Service F (traffic congestion is the result of more traffic flow demand than capacity). Threshold capacity volumes are based on VISSIM average delay results as shown in Figure 4: threshold limits are indicated by vertical red rectangular dotted lines). At oversaturated conditions, all delay values greater than 50 seconds also are shown by red dotted rectangle lines, representing the proposed LOS F threshold for U.S. roundabouts (NCHRP, 2007). As roundabout approach volumes (V_a) and right-turning volume (V_{sl}) increase, threshold capacity occurs at higher volumes, whereas scenario S1 shows a threshold of around 250 to 300 vehicles per hour to be oversaturated for a slip lane yield exit type. An interesting point is that for all bus traffic volumes in these scenarios, threshold values are the same per same scenario. VISSIM analysis shows therefore that the single-lane roundabout operates with a volume/capacity ratio greater than 1.00 regardless of slip lane type. Hence, the slip lane theoretical capacity operational threshold volumes increase with greater right-turn volumes (V_{sl}).

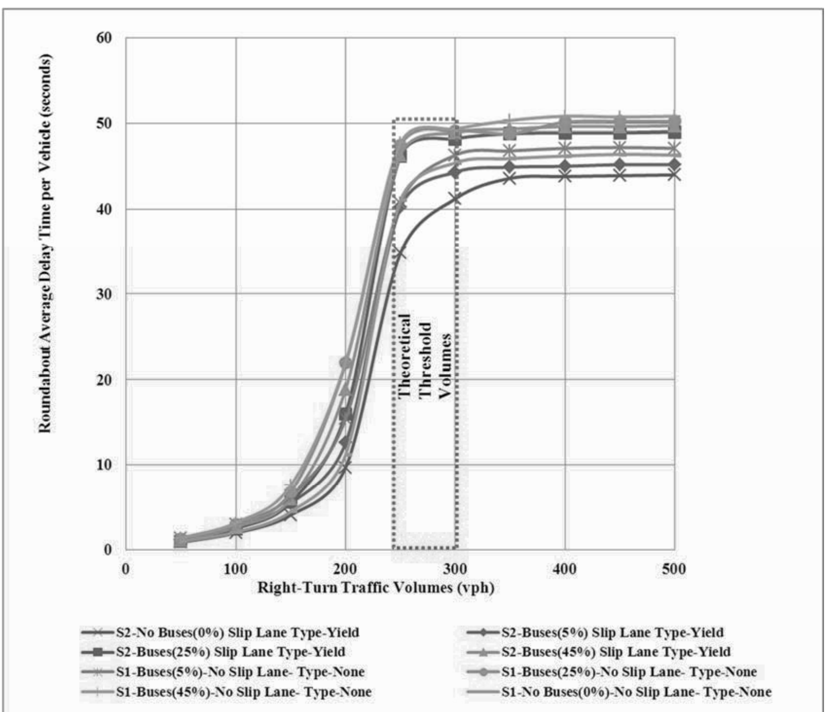


Figure 4. VISSIM Roundabout Average Delay for All Buses, Scenarios S1-S2.

CONCLUSIONS

Based on assumed traffic percentage distribution matrices scenarios, VISSIM results confirm that average delay and circulating conflict volumes in a roundabout with a bus managed slip lane are related exponentially to slip lane volumes and are sensitive to changing bus traffic percentages. Also, the results show that roundabout average delay would improve (decrease) upon implementation of the bus managed dedicated slip lane concept while having minimal impact (reduction) on overall intersection delay. With a yield slip lane exit type, overall roundabout delay was reduced 15% at moderate traffic volumes (V_{sl} =250 vehicles per hour) compared to no slip lane and no buses (Bus0); with increased bus percentages (from no buses to 45% Buses—Bus0 and Bus45), overall roundabout delay was reduced 3%. This observation supports *Hypothesis H1*: a bus lane managed by slip lane type should reduce average delay in a single-lane roundabout. Hence the most effective roundabout delay performance generally is obtained from a yield slip lane exit type compared to no slip lane; as bus traffic volumes increase, delay increases accordingly.

When roundabout traffic becomes oversaturated, any reduction of delay obtained is similar regardless of the bus traffic volumes. Theoretical capacity thresholds values (limits) for right-turning slip lane volumes (V_{sl}) are estimated to be within a range of 250 to 300 vehicles per hour for traffic distribution volumes. This observation supports *Hypothesis H2*: that theoretical threshold capacity volumes increase with increased roundabout right-turn traffic volumes. Hence the most effective roundabout performance generally is obtained from a yield slip lane exit type compared to no slip lane, and as bus traffic volumes increase, delay increases accordingly.

A bus managed dedicated slip lane has shown advantages over no slip lane. These results can serve as guidance for choosing to use a bus managed slip lane and choosing its optimal design.

RECOMMENDATIONS

Determining theoretical threshold value ranges, using VISSIM to examine different bus traffic volumes, can be helpful in planning for roundabout capacity and safety. Practitioners considering the use of a bus managed slip lane in a roundabout design can test multiple traffic volume distribution matrices with other percentages of dominant right-turning traffic (vehicles and buses) to gain insight into different roundabout pattern flows.

Further study can address utilizing dynamic lane assignment to designate an exclusive bus lane on a bus-actuated basis, for both a circulating roundabout lane and slip lane. Potential future research includes evaluation of the impacts of bus stop spacing and/or bus dwell times, bus headway, and pedestrian volumes at slip lane.

Additional analysis should be conducted for other variables: number of lanes within a slip lane (one or two); slip lane widths to accommodate buses (12 ft or 14 ft) and lengths; distance of slip lane exit/merge from the roundabout; number of bus stations;

and other geometric configurations. Finally, it also is suggested that further analysis address other bus managed slip lane exit types such as those using a free-flow exit type slip lane or a ramp metering signal.

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Development of Accident Prediction Model under Mixed Traffic Conditions: A Case Study

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Abstract

Accident prediction models are developed under mixed traffic conditions. Two models have been developed. The first model is a city based traffic accident prediction model. City population and vehicle ownership are the two parameters used to develop the model. A case study of Surat city in Gujarat is taken up. Total accident occurred in the city are regressed with population and vehicle ownership. Second model is the urban arterial based accident prediction model. Past accident record of ring road of Surat city shows that there are eight different locations on a ten kilometer stretch of ring road where the accidents took place consistently. These locations are picked up as accident spots. As there are many contributing factors and causes to road accidents. A comprehensive study of road safety found that human error was the sole cause in 57% of all accidents and was a contributing factor in over 90%. Keeping this in view a new term driver-pedestrian index is used to develop this model. Regression function of Microsoft excel is used for model development. Both the models are checked with R-statistics and t-statistics further the models are validated by using statistical goodness of fit (chi square test). Hence these models can be used to predict number of accidents in future subjected to the same geometric standards. Keeping this in mind improvement measures can be taken up by the district authorities.

Key words: Traffic, accidents, regression, population and vehicle ownership, driver-pedestrian index.

Introduction

Road traffic accidents and their causalities on human being have been the major scourge in both developed and developing societies in the latter half of the twentieth century. Traffic accident is one of the major social problems adversely affecting the welfare and prosperity of developing countries (Baguley et al. 2003). The incidence of road traffic accidents (RTA) is raising world-wide (Eke et al. 2000). As per the commission for Global Road Safety (2009), the road traffic accidents kill an estimated 1.3 million people and injure 50 million people per year globally, and global road fatalities are forecast to reach 1.9 million by 2020. Now a days it is proved that number of accident cases in urban areas are increasing day by day. Due to rapid growth of urbanization, there is a significant growth in number of vehicles. Increased socio economic staus of the people living in urban areas partially reflects on vehicle ownerships, which finally manifest in traffic congestion, encroachment, reduction in vehicular speed, unnecessary delay and significance increase in number of accidents (Kadiyali et al. 1994). In heterogeneous traffic condition, chances of traffic accidents are very high. Forcast for the year 2020 suggests that road accidents as a cause of death or disability would lie at third place out of hundred separately identified causes (WHO 1999).

Literature Review

Hajoti et al. (2011) carried out detailed quantitative analysis on traffic incidents on an Australian road network. The study have considered number of variables to see the considerable effect on incident duration and frequency. Results show that breakdown of vehicles, multiple vehicle crash and debris were the major source of incidents. It was found that incident frequency dropped sharply during weekends whereas rainfall increased the number of incidents. Many researchers have used regression analysis to predict the incident duration. Garib et al. (1997) presented regression model for estimating freeway incident congestion. The incident duration prediction model showed that 81 percent of variation in incident duration can be predicted by number of lanes affected, number of vehicles involved, truck involvement, time of day, police response time, and weather condition. Hadi and Aruldhas (1998) developed an accident model by road-grades. Road length, annual average daily traffic (AADT), lane and shoulder width, types and width of median, existence of curve, grade and number of intersections and speed limit were considered as independent variables. Study concludes that widen the median width on four-lane roads enhanced safety and roads with two-way and left turn median were safer than non-separation roads. Hong et al. (2005) developed accident prediction models for four type of urban road categories which was based on number of lanes, road levels and existence of median barrier. Traffic volumes, number of intersections, connecting roads, pedestrian traffic signals, existence of median barrier were selected as independent variables in a regression analysis. The result reveal that in case of two lane roads, the number of intersections and pedestrian traffic signals were significant variables whereas in case of four lane roads existence of median barrier and number of connecting roads were significant. Cela et al. (2012) used multiple linear regression analysis to find the most significant variables related to the road conditions, time and the main cause which have likely contributed to high rates of accidents in urban areas. Sikdar and Bhavsar (2009) showed that median opening is one of the responsible causes of road accidents because the vehicles travel in the wrong direction (in the opposite carriageway) for a short stretch to avoid travelling the extra distance to take a U-turn at the next median opening.

Accident Scenario in India

In India more than 142,485 persons were killed and 511,394 were injured in about 0.5 million accidents in the year 2011 (Road Transport year book 2011). There is an accident every 65 seconds in India and in every 4 minutes one person dies on the road. The average annual growth of road accidents at national level is 0.6 percent during last ten years. Table 1 shows the accident statistics in India for the period from 2001 to 2011 with accident severity which is the number of persons killed per 100 accidents.

Table 1: Number of accidents and number of persons involved: 2001 to 2011

Year	Number of Accidents		Number of Persons		Accident Severity*
	Total	Fatal	Killed	Injured	
2001	405,637	71,219 (17.6)	80,888	405,216	19.9
2002	407,497	73,650 (18.1)	84,674	408,711	20.8
2003	406,726	73,589 (18.1)	85,998	435,122	21.1
2004	429,910	79,357 (18.5)	92,618	464,521	21.5
2005	439,255	83,491 (19.0)	94,968	465,282	21.6
2006	460,920	93,917 (20.4)	105,749	496,481	22.9
2007	479,216	101,161 (21.1)	114,444	513,340	23.9
2008	484,704	106,591 (22.0)	119,860	523,193	24.7
2009	486,384	110,993 (22.8)	125,660	515,458	25.8
2010	499,628	119,558 (23.9)	134,513	527,512	26.9
2011 (P)	497,686	121,618 (24.4)	142,485	511,394	28.6

(P): Provisional Source: Information supplied by the provinces (Police Department)

Figure within parentheses indicate share of fatal accidents to total accidents.

* Accident Severity: Road Accident Deaths/100 Accidents

Detailed analyses of global accident statistics indicate that fatality rates per licensed vehicle in developing countries are very high in comparison with the industrialized countries. Table 2 shows the comparison between the number of persons killed in industrialized countries and India. It clearly shows that India is far ahead from other developed countries in terms of persons killed in road accidents even with over 130,000 deaths annually; India has overtaken China and now has the worst road traffic accident rate worldwide (WHO 2009).

Vehicle Ownership

The growth rate of vehicles is the backbone of economic development and the Indian automotive industry is the second fastest growing in the world. About 8 million vehicles are produced annually in the country today. In 2011, the country reported 141.80 million registered motor vehicles, a motorization rate of 22 vehicles per 1000

population (Road Transport Yearbook, 2011), in comparison, the United States, the world's most motorization nation reported 675 vehicles per 1000 population.
The motorization rate in India is lower than many developing (Brazil- 222 per 1000 population, South Africa 153 per 1000 population) countries through out the world.

Table 2: Growth of Persons Killed in Road Accidents in selected Countries

Country	**1980**	**1990**	**1997**	**2001**	**2002**	**% Variation between 1997-2002**
Austria	2003	1391	1105	958	956	-13.48
France	13672	10289	7989	8160	7655	-4.18
Germany	15050	7906	8549	6977	6842	-19.96
Hungery	1630	2432	1373	1239	1429	4.07
Italy	9220	6621	6198	6682	6736	8.68
Japan	11388	11227	9640	10060	9575	-0.67
Netherland	1996	1370	1076	993	987	-8.27
USA	51099	44529	41967	42196	42815	2.02
India	24000	54100	76977	80888	84674	6.1

(Source: Handbook on Transportation and road Accidents Statistics, NATPAC, September-2006)

Over the last three decades, motor vehicle numbers have been doubling every ten or fewer years in India as against a 2 % - 5 % annual growth rate in Canada, the United States, the United Kingdom and Japan (Badami, 2009). While motorization rate in India is lower than many developing countries-both in absolute term and relative to size of population, over the last decade, India is experiencing one of the highest motorization growth rates in the world. Motor vehicle growth rate has been largely concentrated in the major cities with Chandigarh being at first place with 82 cars per 1000 population and Delhi holds second rank with 52 cars per 1000 population whereas the average vehicle ownership in the country is 22 vehicles per 1000 population.

Study area profile

Surat is eighth most populous city (urban agglomeration) of India as per the 2011 census (www.censusindia.gov.in) and also one of the fastest growing city. It became a metropolis in 1991, along with eleven other major cities across the country. The statistical data show that during the last eight decades, the city population has grown up from 0.15 million in 1921 to 4.46 million in 2011. The city has registered an annualized GDP growth rate of 11.5 per cent over the past few fiscal years.

Accident scenario in Surat city

Accident scenario in Surat city is shown in Table 3 and Table 4 shows total accident and accident deaths in some other metropolitan cities of India with nearly same or higher population. It explicitly shows that accident severity in Surat is 16 which is near to the other metropolis like Hyderabad, Nagpur, Pune and Jaipur.

Table 3: Accident scenario of Surat city

Year	Types of accidents			Total
	Fatal	Serious	Minor	
1999	173	489	436	1098
2000	138	369	408	915
2001	116	392	359	867
2002	139	425	375	939
2003	144	418	385	947
2004	168	481	397	1046
2005	253	527	345	1125
2006	196	544	386	1126
2007	219	525	408	1152
2008	247	551	424	1222

(Source: District police station)

Table 4**:** Road Accident Profile of selected Metropolitan cities of India (2009)

S. No.	Name of City	Total No. of				Accident Severity*
		Fatal Accidents	All Accidents	Persons Killed	Persons Injured	
1.	Ahmedabad	188	2179	200	2232	9.2
2.	Bengaluru	715	6872	742	5705	10.8
3.	Bhopal	244	3719	272	3152	7.3
4.	Chennai	602	5177	618	4377	11.9
5.	New Delhi	2272	7516	2325	6936	30.9
6.	Hyderabad	465	2990	481	2908	16.1
7.	Indore	394	4724	419	3817	8.9
8.	Jaipur	389	2007	415	1840	20.7
9.	Kanpur	477	1178	533	999	45.2
10.	Mumbai	607	29327	628	6567	2.1
11.	Pune	383	2157	394	1839	18.3
12.	Surat	207	1357	217	1117	16.0

* Accident Severity: Road Accident Deaths/100 Accidents

Model Development

City based Accident Prediction Model

The model can consist of several independent or explanatory variables. In this study, two variables population and number of vehicle of the study area are concerned important for the development of accident model.

Total accident data, population data and number of vehicle data for the city of Surat for a period from 2001 to 2008 are shown in Table 5.

Table 5: Accident, population and per capita no. of vehicle data of Surat city (2001-2008)

Year	Fatal accident	Serious accident	Minor accident	Total accident	Population in million	Number of Vehicles (in million)
2001	116	392	359	867	2.4	0.723
2002	139	425	375	939	3.0	0.803
2003	144	418	385	947	3.1	0.882
2004	168	481	397	1046	3.4	0.975
2005	253	527	345	1125	3.6	1.109
2006	196	544	386	1126	3.7	1.191
2007	219	525	408	1152	3.8	1.295
2008	247	551	424	1222	4.2	1.362

These data were used to develop a multiple linear regression model between the number of accidents and other two variables as shown in equation (1).

$$\mathbf{Y = 401.73 + 108.23\,(X_1) + 271.72\,(X_2)} \qquad (R^2 = 0.98) \qquad \mathbf{(1)}$$

where,
Y = Total number of accidents in a year
X_1 = Population in million in a year,
X_2 = Number of vehicles in million.

The model has an R-square of 0.98, which means that 98 % of the variation in the data explained by the regression line. The t- test also indicates that the model is significant and can be used for the prediction of the number of accidents. Figure 1 also indicates that almost no difference between the predicted and observed value of accidents.

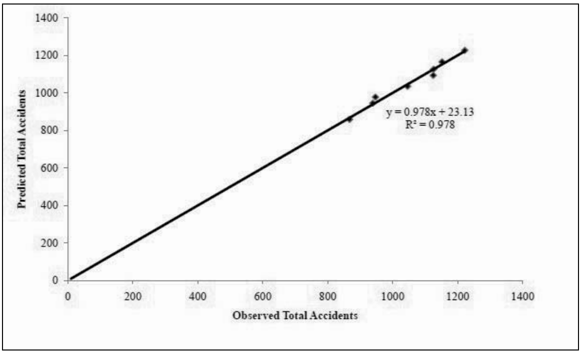

Figure 1: Comparison of observed and predicted accidents

The model is further validated by chi-square test. It is assumed that there is a no significant difference between the observed and estimated number of accidents. The calculated chi-square value for the set of data is **2.28** which is less than the table value of **29.14** at significance level of 0.01 and 14 degree of freedom. Therefore we accept the null hypothesis that there is no significant difference between the observed accident and estimated accident data.

Urban Arterial based Accident Prediction Model

A 10 kilometer stretch of the ring road of Surat city has been selected for the study. This is the major arterial road of the city divides old city to the new city. Accident records over the past six years show that there is a high fatality of accident (Table 7) on this road as compared with other arterial roads also there is a high traffic volume on this road (Table 8). Accident records over a period of six years shows that there are eight different locations namely Athwa gate, Majura gate, Udhna gate, Textile market, Vrushabh Petrol Pump, Sahara gate, Falsawadi and Delhi gate having consistent accident records. These locations have been selected as accident spot on a 10 kilometer stretch of ring road of Surat city and are shown in Figure 2. Accident data of these locations are collected from the respective police stations and are shown in Table 7.

Table 7: Accident records at ring road of Surat city (2003 to 2008)

S. No.	**Location**	**Total Accidents Occurred**					
		2003	**2004**	**2005**	**2006**	**2007**	**2008**
1	Athwa gate	8	13	10	12	10	11
2	Majura gate	11	12	7	10	12	12
3	Udhna gate	10	11	6	10	12	10
4	Textile Market	11	13	19	18	31	21
5	Vrusabh Petrol Pump	4	10	3	2	4	7
6	Sahara gate	10	10	5	9	11	14
7	Falsawadi	10	6	5	8	14	14
8	Delhi gate	9	15	10	5	3	7

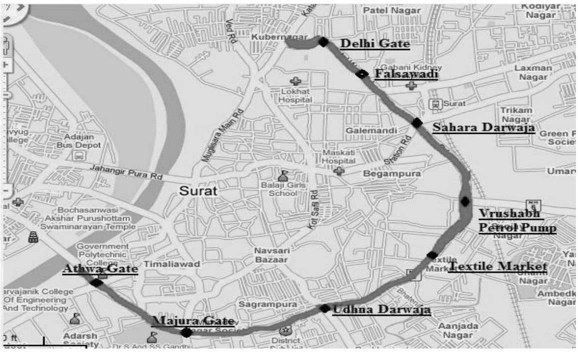

Figure 2: Black spots at ring road section

Traffic volume studies are also carried out at the mid block section of these locations and are represented in Table 8. A model was developed for an urban arterial consisting accident data, traffic volume and driver pedestrian index as the variables. Detail categorization of accident data at these locations are shown in Table 9.

Table 8: Hourly traffic volume data at the respective locations on ring road

Location	2W	3W	4W	Bus	LCV/ HCV	Cycle	Others	Total
Athwa gate	6497	5175	1569	145	480	284	116	14266
Majura gate	5909	4150	1362	123	372	412	150	12479
Udhna gate	3523	4433	619	60	347	343	150	9474
Vrushabh petrol pump	7293	4695	1953	154	495	333	94	15017
Textile market	7773	5040	2090	91	832	329	94	16249
Sahara gate	8554	5330	2240	199	484	359	77	17241
Falsavadi	8282	5250	2151	207	473	296	88	16747
Delhi gate	9648	5701	2384	180	711	357	63	19045

Table 9: Accident data at different spots on ring road section in 2008

Sr No	Location	Fatal Day	Fatal Night	Serious Day	Serious Night	Minor Day	Minor Night	Total Accidents
1	Athwa gate	5	2	3	0	1	0	11
2	Majura gate	6	0	3	1	1	1	12
3	Udhna gate	1	0	5	2	2	0	10
4	Textile Market	2	0	7	2	6	4	21

5	Vrushabh Petrol Pump	1	2	0	0	1	3	7
6	Sahara gate	5	3	3	3	0	0	14
7	Falsawadi	3	1	4	0	3	3	14
8	Delhi gate	0	0	3	1	0	3	7

There are many contributing factors and causes to road accidents. A comprehensive study of road safety (Treat *et al*., 1977) found that human error was the sole cause in 57% of all accidents and was a contributing factor in over 90%. A new terminology "Driver-Pedestrian Index" is introduced in this study which is a measure of driver role as a major cause of accident. The index is measured on an arbitrary scale of 1 to 5 by giving the appropriate rating to the percentage role of driver. The percentage role of driver is calculated based on the percentage of accident measured at a spot. The rating of driver-pedestrian index is shown in Table 10 and 11.

Table 10: % Role of driver

Percentage Accident range	**% role of driver**
1.0-10.0	20
11.0-20.0	50
21.0-30.0	70

Table 11: Rating index of driver and pedestrian

% role of driver	**Rating**
1.0-20.0	1
21.0-40.0	2
41.0-60.0	3
61.0-80.0	4
80.0-100.0	5

Based on the above criteria the driver-pedestrian index calculated at different spots is tabulated in Table 12.

Table 12: Calculation of driver – pedestrian index

Sr. No.	**Location**	**Total accident**	**Percentage accident**	**% of driver role**	**Driver – pedestrian Index**
1	Athwa gate	11	11.46	50	3
2	Majura gate	12	12.50	50	3
3	Udhna Gate	10	10.42	50	3
4	Vrushabh Petrol Pump	7	7.29	20	1
5	Textile Market	21	21.88	70	4
6	Sahara Gate	14	14.58	50	3
7	Falsawadi	14	14.58	50	3
8	Delhi Gate	7	7.29	20	1

Similarly the number of accident and traffic volume reported at a spot is given a rating on a scale of 1 to 5. Accident and traffic volume range and their corresponding rating are shown in Table 13.

Table 13: Range and rating of accident and traffic volume

Accident range	Accident rating	Volume range (vph)	Volume rating
07-09	1	7,500-10,000	1
10-12	2	10,001-12,500	2
13-15	3	12,501-15,000	3
16-18	4	15,001-17,500	4
19-21	5	17,501-20,000	5

The combined rating of accident, traffic volume and driver-pedestrian index as calculated above are tabulated in Table 14. A multiple linear regression model is developed adopting accident as a dependent variable, traffic volume and driver-pedestrian index as independent variables rating.

Table 14: Accident, traffic volume and driver-pedestrian index at the respective locations

Location	Accident rating	Volume rating	Driver and pedestrian index
Athwa gate	2	3	3
Majura gate	2	2	3
Udhna Gate	2	1	3
Vrushabh Petrol Pump	1	4	1
Textile Market	5	4	4
Sahara Darwaja	3	4	3
Falsavadi	3	4	3
Delhi Gate	1	5	1

The accident prediction model for an urban arterial is expressed as:

$$\mathbf{Y = -2.61 + 0.49(X_1) + 1.27(X_2)} \qquad (R^2 = 0.91) \qquad \mathbf{(2)}$$

Where,
Y = Accident rating.
X_1 = Volume rating.
X_2 = Driver-pedestrian index.

The t- test also indicates that all the coefficients are significant the model is significant and can be used for the prediction of the number of accidents. Figure 3 shows the comparison between observed and model predicted accident rating and is well defined by a straight line with R-square as 0.91. Further the model is validated with chi-square test while taking the average number of accident corresponding to the predicted accident rating. It is found that calculated chi-square value for the set of data is **1.17** which is less than the table value of **29.14** at significance level of 0.01

and 14 degree of freedom. Therefore we accept the null hypothesis that there is no significant difference between the observed accident and estimated accident data.

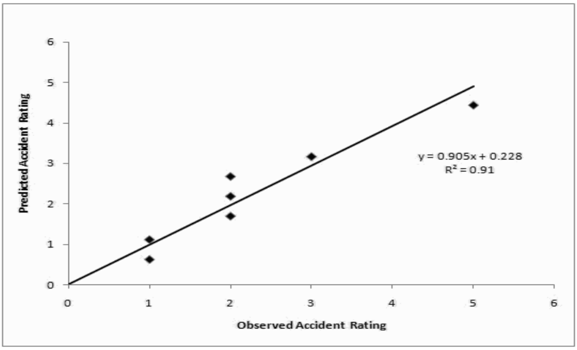

Figure 3: Comparison between observed and model predicted accident rating

Conclusion

The accident prediction model based on population and number of vehicles also the urban arterial based accident prediction model has a very good R-square value of 0.98 and 0.91 respectively. This indicates that there is a perfect correlation between independent and dependent variables. These parameters are found significant at 1 percent level of significance and therefore they are statistically good. The t- test also indicates that the model coefficients are significant and can be used for the prediction of the number of accidents in future and improvement measures can be taken up. However, the transferability of this model to other cities of similar size needs to be checked. As a future scope of work, models can be prepared based on several explanatory variables like road geometry features, time of accident, accident places both commercial or residential weather conditions and many others.

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Performance Enhancement and Congestion Reduction at Busy Signalized at-grade intersection with Bus Rapid Transit Corridor and mixed traffic in India

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Abstract: Bus Rapid Transit (BRT) has emerged as a solution to traffic problems, especially in developing countries where cost is the major criteria to opt for a transit system. However, provision of BRT in existing right-of-way reduces the capacity available for other traffic. The problem gets severe at intersections. This paper presents the effect if bus-way ends at an 'appropriate distance' before the stop line at busy signalized at-grade intersection, and this space of bus lanes are made available to all the traffic (heterogeneous traffic) at intersection. VISSIM, a microscopic simulation tool, has been used to model the heterogeneous traffic and public transit lines under constraints of roadway geometry, vehicle characteristics, Indian driving behaviour and traffic controls. The effect is investigated with different random seeds to obtain reasonable results for analysis. The performance evaluation is done in terms of vehicle throughput, average queue length, maximum queue length, average delay time per vehicle, average speed and emission of Carbon monoxide CO, mono-nitrogen oxides NO_x, Volatile organic compounds (VOC), fuel consumption and energy consumption. It has been observed that availability of bus lanes to other traffic for a reasonable distance before intersection considerably reduces the average queue length, maximum queue length, average delay time per vehicle and emission per vehicle, while there is an increase in vehicle throughput and average speed of all the vehicles. Thus it results in reduction of congestion and performance enhancement of at-grade intersections and network.

Key words: Bus Rapid Transit (BRT),Traffic congestion, intersection, heterogeneous traffic, microscopic simulation, average delay time per vehicle, average speed, queue length, Level of service (LOS).

1. Introduction

Bus Rapid Transit (BRT), also known as High Capacity Bus System, is one of the cost-effective mechanisms for cities to rapidly develop a public transport system (GTZ 2003). BRT is a high-quality bus based transit system that delivers fast, comfortable and cost-effective urban mobility through the provision of segregated right-of-way infrastructure, rapid and frequent operations, and excellence in marketing and customer service (Currie et al. 2006). Since BRT offer transit at a cost much lesser than other options, it is emerging as a desirable mode of transit in developing countries like India. A BRT System is very less capital intensive compared to other popular modes of public transport. It costs 10 to 100 times less than a metro system and approximately 4 to 20 times less than a light rail transit (LRT) system. A BRT project can be planned within a period of 12 to 18 months (Gardner *et al*. 1991). However, urban roads in developing countries have restricted right-of-way (Bhargab *et al*. 1999). Introduction of BRT within the existing right-of-way affects the mobility of motorized vehicles (other than bus) and congestion gets increased in motorized vehicle (MV) lanes. As the buses travel with certain service rate, the dedicated corridor remains vacant for most of the time while motorized traffic on MV lanes suffers from congestion. However, if buses are operated in mixed traffic it is no more rapid transit. Hence, a solution is required to address this problem and optimize the performance of traffic as a whole. The effect of dedicated BRT on MV lanes becomes more noticeable at intersections. Intersections are usually the bottlenecks of the network and are the greatest and immediate source of the traffic accidents. Thus, Level of Service (LOS) at intersection significantly affects the overall LOS of road (Lakkundi *et al.* 2004). The critical aspect of increasing the throughput of any road system lies in increasing the throughput of the intersection. Thus, optimization of traffic performance as a whole, at intersection is required so that BRT may not greatly reduce overall potential capacity of system at intersection; at the same time, merits of BRT as rapid transit may be maintained.

So far, various literatures present studies only to defend BRT as a solution to traffic problems. However, the countries which are opting for BRT realized that BRT is a solution at the cost of congestion of other motorized traffic. Thus it is in fact, a shifting of congestion from one mode to other. Hence, there is a requirement of optimization of traffic as a whole so that all the modes may get advantage from the solution and there may be maximum relieving of congestion. This paper presents one of such investigation.

Traffic in most of the developing countries as well as in some developed countries, is highly heterogeneous, comprising of different types of vehicles with widely varying static and dynamic characteristics (Arasan *et al.* 2008). Traffic simulation is a powerful and cost-efficient tool for traffic research, testing different alternatives and evaluating them. The simulation model allows to predict the outcomes of a proposed change to the traffic system before it is implemented, and to evaluate the proposed solution (Velmurugan *et al.* 2010). Thus, in order to study the behaviour and various interactions at intersection, simulation studies are done. In this paper microscopic simulation tool VISSIM (version 5.3, official license available) is used to model urban traffic. VISSIM is a microscopic, time step and behaviour based simulation tool. The program can simulate multi-modal traffic flows, including cars, goods vehicles, buses, heavy rail, trams, light rail, 2-wheelers (scooter, motorcycles), 3-wheelers (auto rickshaw, tuk-tuk), bicycles and pedestrians. VISSIM has been used to model the heterogeneous traffic and public transit lines under constraints of roadway geometry, vehicle characteristics, Indian driving behaviour and traffic controls (PTV Vison 2010).

The paper presents the effect if bus-way ends at an ‘appropriate distance’ before the stop line at busy signalized at-grade intersection, and this space of bus lanes is made available to all the motorized traffic (heterogeneous traffic) at intersection. The performance evaluation is done in terms of vehicle throughput, average queue length, maximum queue length, average delay time per vehicle, average speed and emission of Carbon monoxide CO, mono-nitrogen oxides NO_x and Volatile organic compounds (VOC). The effect is investigated with different random seeds to obtain reasonable results for analysis. It is observed that availability of bus lanes to other traffic for a reasonable distance before intersection considerably reduces the average queue length, maximum queue length, average delay time per vehicle and emission per vehicle, while there is an increase in vehicle throughput and average speed of all the vehicles(in network). Thus it results in reduction of congestion and performance enhancement of at-grade intersections and network. The reduction of emissions per vehicle may be translated in reduction of Carbon-dioxide which may lead to earning of carbon credits.

2. Simulation model

VISSIM uses the psycho-physical driver behaviour model developed by WIEDEMANN (PTV Vison 2010). The basic concept of this model is that the driver of a faster moving vehicle starts to decelerate as he reaches his individual perception threshold to a slower moving vehicle. Since he cannot exactly determine the speed of that vehicle, his speed will fall below that vehicle's speed until he starts to slightly accelerate again after reaching another perception threshold. This results in an iterative process of acceleration and deceleration. Stochastic distributions of speed and spacing thresholds replicate individual driver behaviour characteristics. VISSIM's traffic simulator not only allows drivers on multiple lane roadways to react to preceding vehicles, but neighbouring vehicles on the adjacent travel lanes are also taken into account. Moreover, approaching a traffic signal results in a higher alertness for drivers at a distance of 100 meters in front of the stop line. VISSIM simulates the traffic flow by moving "driver-vehicle-units" through a network. Every driver with his specific behaviour characteristics is assigned to a specific vehicle. As a consequence, the driving behaviour corresponds to the technical capabilities of his vehicle. Attributes characterizing each driver-vehicle-unit are (1) Technical specifications of the vehicle, e.g. length, maximum speed, potential acceleration, actual position in the network, actual speed and acceleration (2) behaviour of driver-vehicle-unit, e.g., psycho-physical sensitivity thresholds of the driver (ability to estimate, aggressiveness), memory of driver, acceleration based on current speed and driver's desired speed (3) interdependence of driver-vehicle-units, e.g. reference to leading and following vehicles on own and adjacent travel lanes, reference to current link and next intersection, reference to next traffic signal(PTV Vison 2010).

3. Data collection

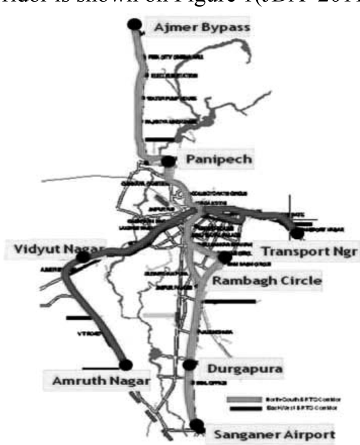
In order to have conclusion from the investigation which may be relevant in international context, study area is chosen as Jaipur. Jaipur, the capital city of Rajasthan state in India has population more than 3.6 million and has population density of 5000 persons per sq km. The total developed area of Jaipur is 541 sq km. The female and male ratio is 0.876:1 and literacy ratio is 69.9%. As per latest officially published data, in 2005-06 total vehicles in Jaipur were 1.04 million with growth rate of 12.6%. The composition of vehicles based on ownership is approximately 14.8% car/jeep, 75.3% two wheeler, 1.2% three wheeler (auto-rickshaw), 1.7% buses and 7.0% goods vehicles including tractors. The modal share is 26% walk, 6% cycle/cycle rickshaw, 27% 2-wheeler, 8% car, 6% auto rickshaw (three wheeler), 8% taxi, 18.5% bus transport and 0.5% train. The arterial, sub-arterial and other important road length in Jaipur is approximately 600km. Out of which 18% has right of way (ROW) less than 30m; about 32% has ROW of 30m while remaining has ROW more than 30m but less than 54.5m. Most of these roads have volume to capacity ratio (v/c) more than 1 and has no scope for widening. The imbalance between growth of vehicles and road network emerged in heavy traffic congestion and reduced vehicle speed. There are number of roads in Jaipur where traffic congestion is a regular and daily phenomenon (Master Development Plan2025

2010). Such situation exists in many cities all over the world. Table 1 shows the characteristics of some of the main roads (arterials) of Jaipur city.

Table 1 : Characteristics of main roads of Jaipur city

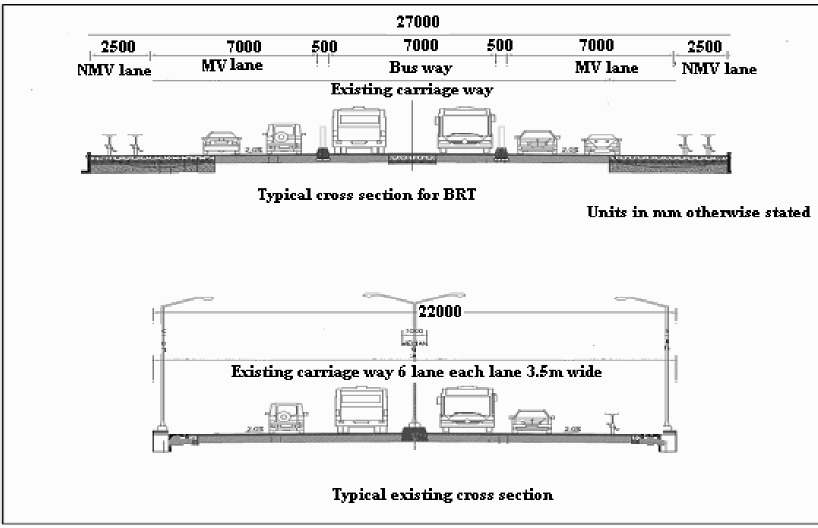
S.No.	Name of Road	Volume/ Capacity ratio	Level of Service for peak hour (LOS)
1	Tonk Road	1.32	F
2	Sahkar Marg	1.29	F
3	MI Road	0.96	E
4	Ajmer Road	1.3	F
5	Sikar Road	0.97	E

In order to provide rapid public transit in Jaipur, Bus Rapid Transit (BRT) was introduced in 2010.The BRT master plan for Jaipur city includes three phases (1) Phase-I :Sikar Road to Tonk Road - North-South Corridor and Ajmer Road to Delhi Road - East-West Corridor . Under this phase North-South Corridor for 7.1 km (Package IB) from C-Zone Bypass near Harmada to Pani Pech has been developed and is operational. The ROW of this section ranges from 40-50m (2) Package II: (Pani Pech to Laxmi Mandir, & Sahkar Bhawan to Sanganer , via Ram Bagh Circle & Tonk Road) 16 km with ROW 20-40m : An Elevated BRT has been proposed between Panipetch & khasa-kothi so as to facilitate connectivity to Sindhi Camp Bus Stand (which is the central bus stand for Jaipur city) and Railway Station. Construction of elevated road at Durga-pura is in progress with provision of future Metro on Tonk Road. (3)Package III:East-West Corridor (Amrut Nagar to Govt.Hostel via:c-zone Byepass,Queen's Road Jn. & Sodala) for 13.35km with ROW of 18-35m. In this package work of at grade BRT from Mansrovar to Queen's Road is commenced & Elevated Road on Ajmer road including Metro on Tier II[nd] is being taken up through Jaipur-Metro. There is an extension of the corridor in south-east direction to connect the sanctioned corridor under Package II at EP junction on Tonk road which is about 1 km from the airport. The length of this stretch of extended corridor shall be 2.7 kms out of which 1.1 km will be elevated road. The location of the BRT corridor is shown on Figure 1(JDA 2011).



(a)

Bus Lane	Motorized Lane	NMV Lane
Middle side 3.5m wide	7 to 9m	2 to 2.5m

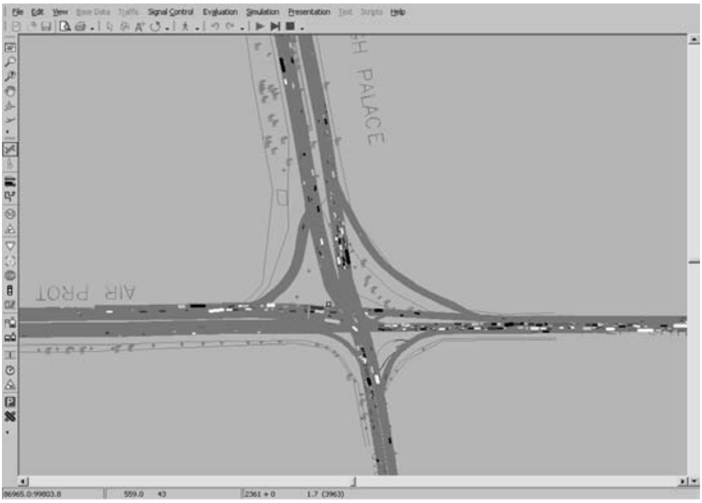


(b)

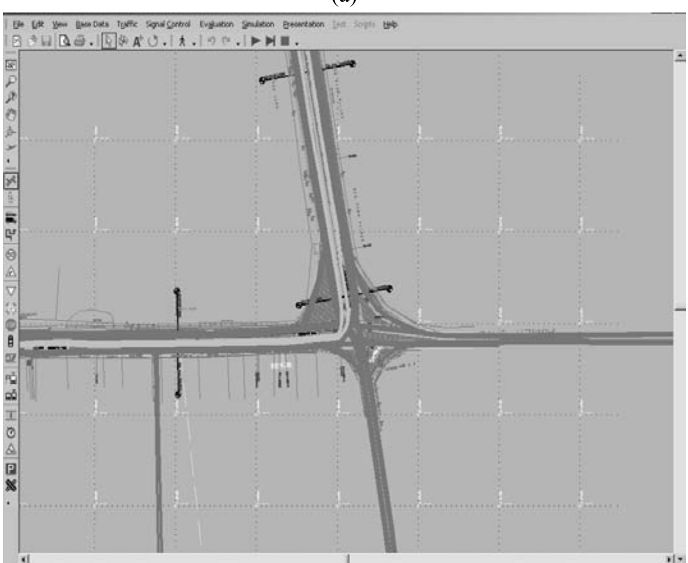
Figure 1: (a) BRT Corridor –Jaipur (b) typical cross-section of BRT Jaipur at Rambagh Intersection

Rambagh intersection is one of the busiest at-grade signalised intersections in Jaipur and handles a large number of vehicles and pedestrians and witnesses daily traffic congestion. It is the part of package –II of BRT. Henceforth, it was chosen to optimize the performance of intersection by making proposed BRT corridor available for all vehicles for some reasonable distance before intersection. The entire geometry of the intersection was measured to replicate the intersection in simulation. Eight cameras were used to capture traffic at intersection on all approach roads in the same time interval; with placement of two cameras on each approach road. The cameras were placed in such a manner that one camera observed the through and right turning traffic (hence queue length), the other recorded the vehicle coming in to the left turning lane till the point they merge with the traffic coming across. The synchronization of two camera data provided traffic data for traffic composition, traffic moving through, right and left, queue length as well as time spent by vehicle in queue. The data was supplemented with manually collected data on road geometry and classified traffic survey to cover any omission during video recording. Travel times of vehicles going straight and turning right are also collected. The travel times were measured as the time taken to travel from first reference line (distance of 110m from stop line) to second reference line (stop line). Stop watch was started when front wheels of a vehicle crossed the first reference line and stopped when same wheels of the vehicle crossed second reference line. The traffic surveys were carried out during the peak period of 5.30 pm to 6.30 pm. The peak 15 minutes data of this ‘peak period’ is used for simulation by multiplying it by 4 to get hourly data. In

Figure 2 the Rambagh intersection at Jaipur, India is shown and Table 2 incorporates the traffic data. The v/c ratio of roads (at this intersection) proposed to accommodate BRT is 0.71 for road towards stadium and 0.95 for road towards Ambedkar circle.



(a)



(b)

Figure 2: Rambagh Junction simulation (a) existing intersection (b) with proposed BRT

Table 2: Traffic data existing intersection

Approach	*Traffic composition (% vehicle)*												*Through (% vehicle)*	*Right turning (% vehicle)*	*Left turning (% vehicle)*	*Total volume (veh/hr)*
	Car	*taxi*	*SUV*	*ambulance*	*utility*	*Minibus/van*	*Bus*	*LCV*	*3*-wheeler*	*2**-wheeler*	*bike*	*Indian cycle rickshaw*				
From Stadium	20.5	3	4	0.5	1	4	6	3	9	46	2	1	55.56	22.22	22.22	1758
From Ajmeri-gate	20.5	3	4	0.5	1	4	6	3	9	46	2	1	50.00	20.00	30.00	3062
From JDA circle	22.5	3	4	0.5	1	4	6	3	10	43	2	1	53.85	30.77	15.38	1580
From Ambedkar circle	22.5	3	7	0.5	1	4	6	3	10	40	2	1	25.00	37.50	37.50	2312

*Auto-rickshaw (Indian) ** motorcycle and scooter

4. Model calibration and validation

The model construction procedure consists of (i) identification of important geometric features (ii) collection and processing of traffic data (iii) analysis of mainline data to identify recurring bottlenecks (iv) VISSIM coding (v) calibration based on observations from (iii). Calibration is the process by which individual components of simulation model are refined and adjusted so that simulation model accurately represents field measured or observed traffic conditions. With regard to calibration, traffic simulation model contain numerous variables to define and replicate traffic control operations, traffic flow characteristics and driver behaviour. VISSIM simulation model contains default values for each variable, but also allows a range of user applied values for each variable. These variables are changed as per field measurements and observed conditions (PTV Vison 2010).

The geometry of existing Rambagh intersection was created using links and connectors which are the building blocks of VISSIM network. The number of lanes per road and width of each lane, left turning lanes on each approach road, central median, traffic islands and other road features were specified as per existing. After creation of network, the vehicle input for various links was given. This is followed by specifying the various routes in which vehicles travelled and the volume of these vehicles in each route is specified. The other features viz. positioning of speed limits, conflict zones, stop signs, signal heads are specified as per existing. The data collection points, travel time sections, queue counters and nodes are placed. The Indian driving behaviour (Table 3) is calibrated for the following parameters: standstill longitudinal distance between the stopped vehicles, headway time in seconds, following variation which restricts the longitudinal oscillation and indicates how much more distance than desired distance a driver allows before he intentionally moves closer to vehicle in front, threshold for entering 'following' controlling the start of deceleration process, following threshold which controls the speed differences during the 'following' state, speed dependency of oscillation, oscillation acceleration, standstill acceleration, minimum headway, maximum deceleration of vehicle and trailing vehicle for lane change, overtaking characteristics, minimum lateral distance at different speeds, waiting time for diffusion. The Indian vehicles (Figure3)are calibrated for desired speed distribution, weight distribution, power distribution and model distribution. The links are assigned behaviour according to driving behaviour. On Indian roads, because of heterogeneity of traffic, it is difficult to enforce lane discipline. Hence, vehicle occupies lateral positions on any part of road based on space availability; overtake within lane from both the sides. The validation of the model was carried out by comparing maximum queue length simulated by model for existing intersection on each approach road with field observed values. The simulation model was given multirun with 20 random seed numbers and average of 20 simulation runs was taken as final output of the model. The value of t-statistic, calculated based on observed data (t_o) for all the four approach road is below 2.00. The critical value of t-statics for level of significance of 0.05, at 19 degrees of freedom is 2.093. Thus, value of t-statistic, calculated on the basis of observed data, is less than the corresponding table value. This shows that there is no significant difference between the simulated and observed average queue lengths.

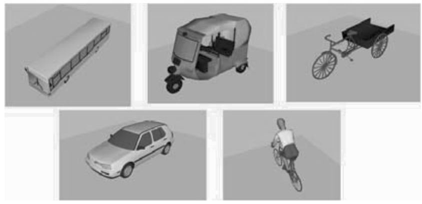
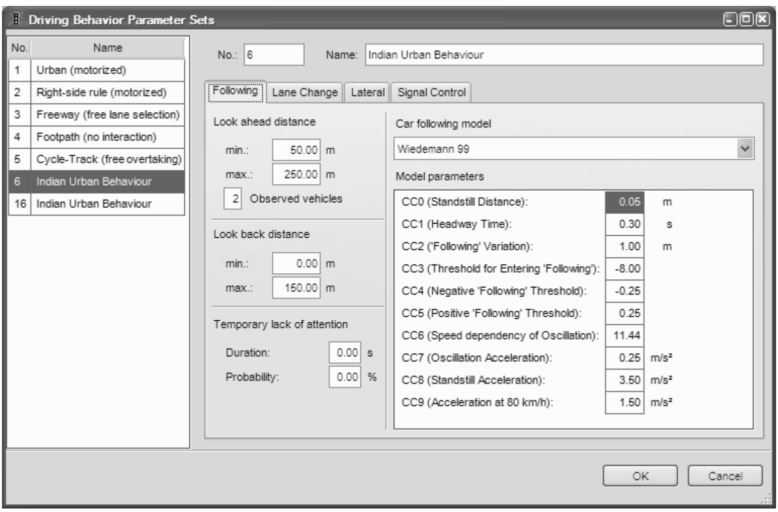


Figure 3: some of vehicles

Table 3: Driver Behaviour



5. Performance evaluation of intersection with dedicated BRT corridor v/s modified (modified BRT with bus lanes open to all motorized vehicles at intersection)

The model validated as above is used to study the effect if BRT (to be) provided at intersection is modified such that dedicated bus ways are allowed to other traffic for some distance (75m) before intersection. This distance is reasonable distance to make study while not disturbing BRT in major way. The criterion fixed to find out this distance is not to reduce speed of BRT buses in network more than 4% so that rapid transit feature of BRT is not disturbed and public transport will remain priority as earlier.

Evaluation of performance of intersection is carried out for measurements of effectiveness (MOEs) such as average queue length, average delay per vehicle, emissions (CO , NOx ,VOC), fuel consumption , maximum queue length , number of vehicles etc. The MOEs are plotted for both the cases to appreciate the changes when bus lanes are made available to all the motorized vehicles for length of 75m before intersection. Figures Fig (4) to Fig (10) are arranged all together for reader's convenience and the results are interpreted after the figures.

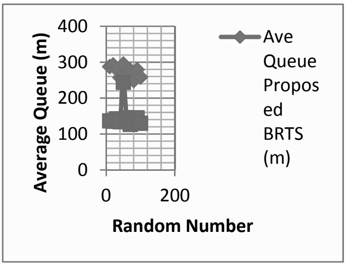


Figure 4: Comparison – Average Queue Length

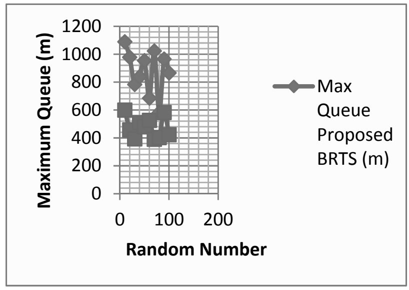


Figure 5: Comparison-Maximum Queue Length

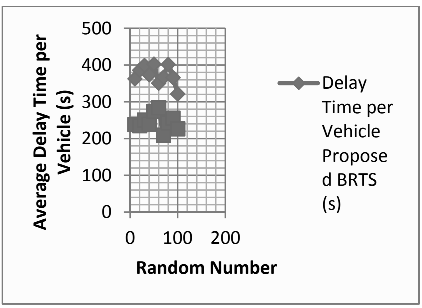


Figure 6: Comparison -Delay time per vehicle

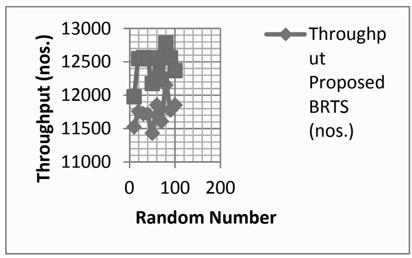
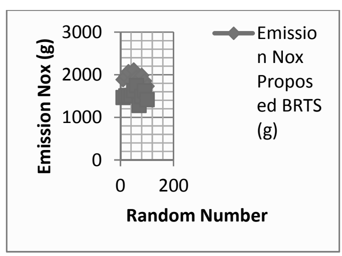
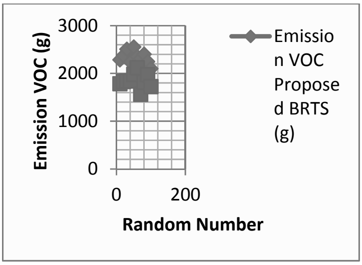


Figure 7: Comparison-Throughput

(a)



(b)



(c)

Figure 8: Comparison- Emission (a) CO (b) NO_x (c) VOC

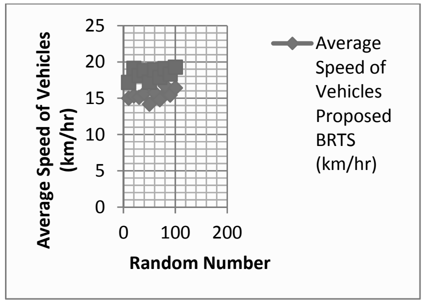
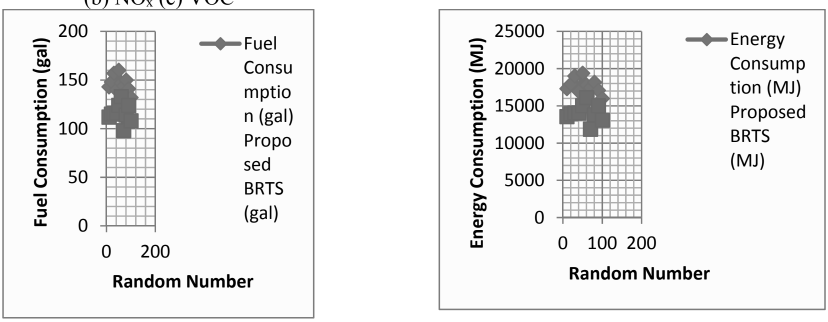


Figure 9: Comparison- Average Speed



(a) **(b)**

Figure 10: Comparison – (a) Fuel Consumption and (b) Energy Consumption

Figure 4 to Figure 10 shows net effect if bus-way ends in good time (75m) before the stop line at busy signalized intersection, and dedicated bus lanes are made available to all the traffic (heterogeneous traffic) at intersection. Figure 4 shows that average queue length decreases significantly by approx. 45%. Figure 5 shows that maximum queue length is reduced by 46%. Figure 6 shows that average delay time per vehicle gets reduced by approx 34%. Figure 7 show that throughput is increased by 5.5%. Figure 8 depicts the effect on emissions. Emissions are reduced as the average delay time is reduced; however, it gets increased when the number of vehicle passing through intersection increases. The net effect is the reduction in emission by 20%. Figure 9 shows that average speed of vehicles in the network gets increased by approx. 19%. It increases from 15.45 km/hr to 18.40 km/hr. Figure 10 shows the effect on fuel and energy consumption. There is a net decrease in fuel and energy consumption which is approx 18%. The performance of BRT was also analysed for the proposed modification. The BRT with service frequency of 10 minutes time suffers reduction in speed of buses in network from 25 km/hr to 24.1 km/hr. Thus there is reduction of 3.6%. Since the loss of BRT is small for the network, the rapid transit feature of BRT within network is still maintained.

Conclusion

BRT is an innovative, high capacity, lower cost public transit solution that aims to improve urban mobility. However, introduction of BRT in existing restricted right-of-way creates conflict of interest with other modes and it seriously hampers the mobility of other vehicles. Thus in order to derive the benefits of BRT without adversely affecting other motorized vehicular traffic, optimization of road system at intersection is required. In case of busy signalized at-grade intersections with BRTS corridor, if bus-way ends in good time before the stop line and dedicated bus lanes are made available to all the motorized vehicles (heterogeneous traffic) at intersection, there is significant decrease in average queue, maximum queue length and average delay time per vehicle. The throughput gets increased and there is a significant reduction in emissions and fuel consumption. The average delay time per vehicle gets reduced by approximately 34% and the average speed of vehicles in the network gets increased by approximately 19%. This solution can bring about significant improvement in the performance of intersection and network.

Acknowledgement

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Benefits of Productivity Growth in Rail Transit Construction: The Washington Metro Experience

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Abstract

Modern rail rapid transit projects represent major capital investments, reflective of their complex technical nature in a diverse and highly developed urban landscape. They pose significant challenges in design, engineering, constructability, and contracting that must be overcome for successful completion. However, as compared to equivalently scoped projects built 25 to 30 years ago, today's projects, when effectively managed, are more likely to:

- Satisfy higher safety, quality, and level of customer service requirements;
- Provide higher community acceptance;
- Initiate passenger service 30-35% faster from contract award; and
- Cost 25-30% less in comparable dollars.

The trends in this study are derived from an extensive and well-tested database of 30 years of transit construction projects on the Washington Metrorail System. Though the trends draw largely from productivity gains in the overall U.S. construction industry, they still deserve to be acknowledged in discussions about the increasing value of rail rapid transit projects. These patterns can strengthen cases made on the grounds of environmental or economic development benefits.

Many U.S. rail transit systems, notably many light rail transit (LRT) systems, have pursued aggressive expansion in recent decades. This study should encourage transit agencies or other researchers to conduct similar examinations of cost and productivity trends. Additional cases similar to the one presented here would be useful for the industry in demonstrating the increasing efficiency and value of rail transit projects.

This paper does not present a forecast of future conditions; it is intended to highlight important advances being made in the U.S. engineering and construction industry for public transit projects. Although construction cost trends appear to satisfy the goal of better-faster-cheaper, much work remains in ensuring these advances continue over the next 30 years as population grows and mobility challenges evolve.

Introduction

Modern rail rapid transit projects, like extending Metrorail in the U.S. capital region, are advanced through a multi-year rigorous environmental process, political consensus building, complex funding approvals, highly litigated private property acquisitions, and extensive public outreach. These projects represent major capital investments and are complex infrastructure undertakings constructed in diverse and highly developed urban environments.

Rail rapid transit construction projects worldwide and in the U.S. especially, have come under attack as being very costly. Clichés like "Metrorail costs out of control," appear frequently in anti-transit, auto/highway promotional media and/or in literature provided by those "pushing" projects to lower capacity modes (i.e., bus rapid transit) and/or High-Occupancy/Toll (HOT) Highway Lanes.

It is beyond the scope of this paper to defend Metrorail against myths and negative clichés by detailing the significant benefits derived from these investments in terms of speed and capacity and/or overall community value. Rather, this paper strongly counters the notion that building Metrorail today would be prohibitively more expensive as compared to equivalent projects built 25, 30 or 35 years ago.

Over the last quarter century, our society as a whole has increased **R**egulatory requirements, demanded higher **P**erformance-based services and continually asked for improved **C**ustomer service. This **RPC** factor can add significantly to the total cost and time frame of project implementation. Despite this, Metrorail construction trends have appeared to satisfy the **BFC** goal: **Better-Faster-Cheaper**, as compared to equivalent scope projects built 30+ years ago, based on this study of the Washington Metrorail System.

Metrorail projects built today, compared to equivalently scoped projects built 30 years ago, are more likely to satisfy higher safety, quality, and customer service levels; provide higher community acceptance; utilize advanced technology, circuitry, and material; initiate passenger service 30-35% faster; and cost 25-30% less in comparable dollars. These trends have created an outstanding value. Every five years approximately 1 billion passenger trips are safely and reliably accommodated by the 107-mile, 86-station Metrorail System in the Washington, DC region.

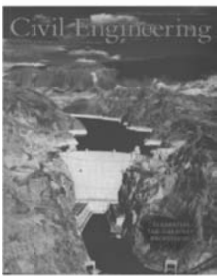
Metrorail construction projects have realized significant cost and time reduction gains consistent with overall U.S. construction industry productivity gains. Factors primarily affecting construction productivity are real wage trends, project management, technology and analytical methods, contracting innovations and competition, owner organization, design standardization, labor organization, skills and training, project uniqueness, and funding and oversight.

Although general productivity gains significantly benefited rail transit construction, these projects are still expensive because their general productivity rates are still below what economists call the *"potential growth rate"* and are a *"drag"* on the overall project budget. The cause for this lack of overall improved productivity gain is complex and varied. Rail transit construction is not immune from the main issues slowing productivity gains down, the so called "grandma syndrome" – a reluctance to abandon tried and tested processes.

Background

In 2011, approximately 750,000 passengers daily used the 86-station, 5-line, 170 km Metrorail System in the U.S. Capital Region (Washington, DC/MD/VA). In November 2002, Civil Engineering Magazine listed WMATA's Metrorail system as one of the 40 projects of the century, see Figure 1 below.

Figure 1-One of 40 Projects of the Century



WMATA's Metrorail System is a landmark in civil engineering history, one of the 40 projects of the century recognized in November 2002 by the American Society of Civil Engineering. Among its peer projects are the Hoover Dam, the Panama Canal, the Empire State Building, the Brooklyn Bridge, the Golden Gate Bridge and the Erie Canal.

The replacement value of the WMATA Metrorail System exceeds $25 billion today. Metrorail engineering and construction is considered the largest single project of its type in the U.S.

The infrastructure of the 2-track network includes 85 km of underground (35 km of cut and cover box and 45 km of bored tunnel), 73 km of surface and 12 km of aerial structures, including several bridges and four underwater structures. The infrastructure includes almost 60,000 parking spaces at stations; 21,000 or which are located in 15 multi-level parking structures. The Metrorail System also includes 100 traction power substations supplying 700 million kWh of power. In addition, the system is operated via 100 fully automatic train control based interlockings, 8 railcar storage and maintenance yards, almost 600 escalators, 220 elevators, and 1,000 railcars. It features hundreds of communications facilities, scores of ventilation shafts, extensive station air conditioning (chiller plants) and hundreds of appliances required for underground water disposal from the tunnels.

Figure 2: Washington Metropolitan Area Transit Authority System Map

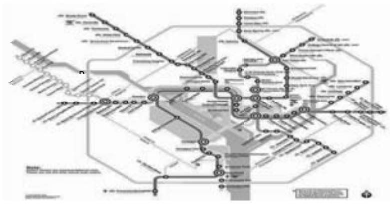
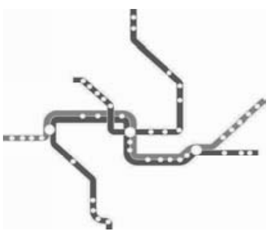


Figure 3: Metrorail Network Development

135 Million Labor Hours of Construction; 3 Phases Completed.
4th Underway to the Washington Dulles International Airport

Phase I: 1972 - 1982

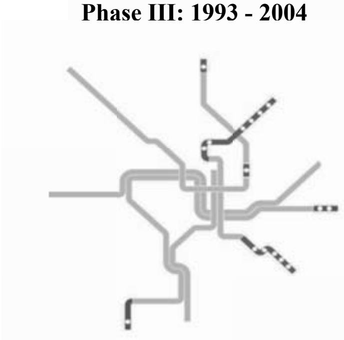


39 Miles; 43 Stations; $ 8 Billion;
90 Million Construction Labor-Hours Worked

Phase II: 1983 - 1992

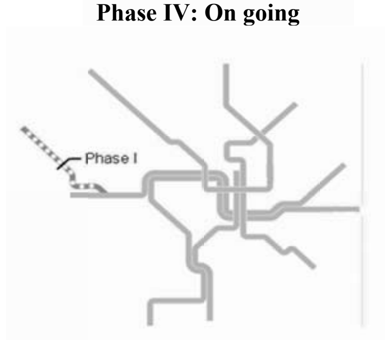
42 Miles; 27 Stations; $ 7 Billion;
24 Million Construction Labor-Hours Worked

Phase III: 1993 - 2004



26 Miles; 16 Stations; $3.6 Billion;
$21 Million Construction Labor-Hours Worked

Phase IV: On going

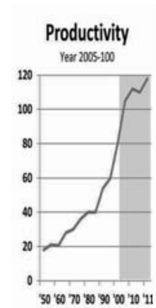


Silver Line Extension to Dulles Airport and Loudoun County, 23-miles, 11-stations,;
(Phase 1; 12 Miles; 5 Stations; to be Completed 2013;
Phase II to be Completed 2016)

*__NOTE__: The Metropolitan Washington Airports Authority (MWAA) is the manager for the Silver Line Extension, under special governmental agreement.

Productivity Analysis

America is more productive today than at any other point in history because it is more efficient at producing goods and services. In 1870, the typical U.S. household required 1,800 hours of labor just to acquire its annual food supply; today it takes about 260 hours of work. Despite falling employment, American factories' output is up because productivity has climbed steadily though workers' wages and benefits have not increased much; productivity is up 40.4% since 2001.



Source: US Labor Department

Productivity reflects the joint efforts of many influences such as, changes in technology; capital investment; the level of output; utilization of capacity, energy and materials; the organization of production; managerial skills; and the characteristics and efforts of the work force. Rising productivity indicates less time involved per unit of output, a favorable sign of efficient use of resources in the economy. Gains in productivity reduce costs and can lead to both lower prices, as well as higher real wages.

Overall U.S. productivity has grown at an annual rate of more than 2% per year on average over the last 40 years. Strong productivity growth is another reason for low inflation. Construction, in general, is a major beneficiary of low and stable inflation. When productivity grows at 2.7% a year, the standard of living doubles every 27 years; at 1.4% it doubles every 51 years; at 5% it doubles every 14 years.

The factors that influence productivity gains in the rail transit construction industry include market size, structure, competition and customization. Although not the only indicator, construction project duration is an important measure of overall productivity. The results of an analysis of Metrorail System construction duration by major element is in the final table in this section. These data indicate that most project elements have experienced considerable productivity gains. Related cost savings are analyzed in the following section.

Figure 4: Primary Factors in Rail Transit Construction Productivity

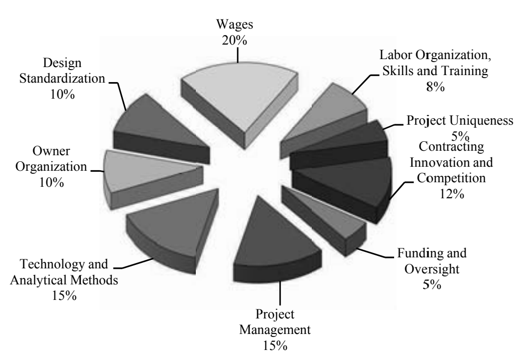


Figure 5: Construction Project Duration by Major Element

Element Number	Basic Project Element*	Built in 1970's Duration in days	Built in late 1990's/2000's Duration in days	Percentage Change in Duration
1.	Real Estate	N/A	N/A	N/A
2.	Cut and Cover Station	1,530	1,124	-27%
3.	At-Grade Station (excl. of line/trackwork/systems)	790	780	-1%
4.	Aerial Station (excl. of line/trackwork/systems)	1,374	1,050	-24%
5.	Parking Structures	820	609	-26%
6.	Cut & Cover Lines (excl. of Trackwork/Systems)	780	860	10%
7.	At-Grade Lines (excl. of Trackwork/Systems)	1,095	930	-15%
8.	Aerial Lines (excl of Trackwork/Systems)	1,095	1,050	-4%
9.	Tunnel Line (excl. of Trackwork/Systems)	1,715	1,140	-34%
10.	Automatic Train Control	1,953	1,075	-45%
11.	Communications	818	827	1%
12.	Running Track	760	820	8%
13.	Trackwork: Double-crossover	760	820	8%
14.	Trackwork: Equilateral Turnout	760	820	8%
15.	Traction Power	850	840	-1%
16.	Elevators	792	492	-38%
17.	Escalators	792	492	-38%
18	Fare Collection	577	547	-5%
19.	Railcars	2,809	1,296	-54%
20.	Rail Yards	947	960	1%

Cost Analysis

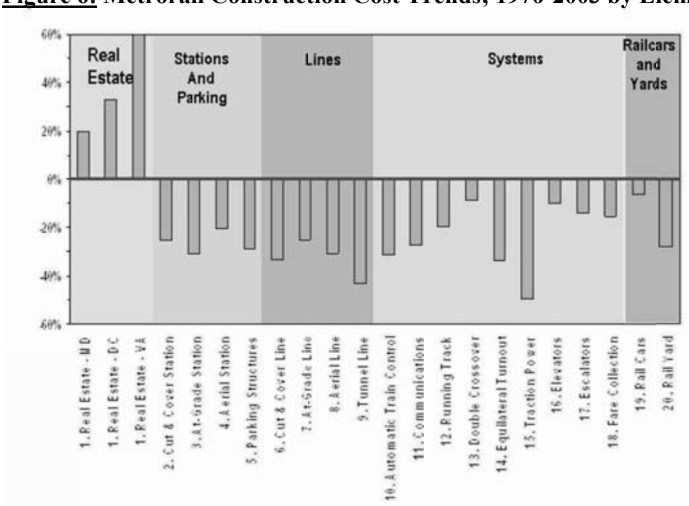
Rail transit customers today are far more demanding and discriminating consumers than at any other time in American history. Though U.S. median household income fell over the last decade when adjusted for inflation due to the troubled economy, median household income has grown substantially since construction began on the Metrorail System. As reported by the U.S. Census Bureau, median household income in 2010 dollars increased from $43,479 in 1975, $44,616 in 1980, and $48,423 in 1990 to $49,445 in 2010. In a related trend, the U.S. now has more vehicles than licensed drivers. In 2009, there were 1.19 vehicles per licensed driver, compared to 1.07 in 1990 and 0.96 in 1980. These rises in standard of living require rail transit projects to offer substantial mobility advantages if they are to attract users and achieve societal benefits. However, higher levels of speed, comfort and convenience all come with higher levels of project cost.

Rail transit projects that are advanced to construction fully satisfy all environmental regulations and reach a local consensus during the lengthy environmental process for the final selection of the project. This public dialogue often leads to cost increases, changes in scope, and expansion or enhancements to satisfy system users and non-users. Adding amenities into project designs increases project costs, but ultimately this process leads to a better project with higher community acceptance.

Along with the cost demands made on rail construction projects, the overall value of construction continues to increase significantly each year. The U.S. market represents about one-quarter of the world's total $3.4 trillion construction market. Total construction employment is more than 6.7 million workers (about 6 percent of the nation's total non-farm, private sector employment). The U.S. annual construction rate is now in excess of $807 billion (U.S. Census Bureau, U.S. Department of Commerce, November 2011; U.S. Census Bureau News, January 3, 2012).

Yet despite these increasing expenditures and cost demands, Metrorail construction has become systematically more efficient and less expensive due to increases in productivity. Nearly 80¢ of each dollar invested to build the Metrorail System went to construction contracting, real estate acquisition, procurement of railcars to run passenger service and payment for insurance coverage; this spending is supplemented by investment in project design services and project management cost by the agency. Twenty major elements account for more than 95% of the total cost for a typical Metrorail construction project. These elements can be grouped into five basic categories; real estate; stations and parking; lines; systems; railcars and yards.

<u>Figure 6:</u> Metrorail Construction Cost Trends; 1970-2003 by Element



These trends are derived from an extensive and well-tested database, unparalleled in the U.S. rail transit industry. This chart represents an initial assessment, a work in progress, of a **"check-the-trends"** study, and may result in more refined and further validated future studies. Any attempt to draw strict numerical conclusions at this phase of the study may result in errors. These trends, although approximations, give a sense of direction, general patterns, and overall performance insight.

These costs are only construction contracting costs except element #1, which represents an average real estate acquisition price. These costs are based on completed construction contract values. It should be emphasized again that the purpose of this tabulation is not to establish numerical conclusions; it is only to **"check-the-trends"** of Metrorail construction costs, based on true, apple-to-apple comparisons.

Figure 7: Cost Comparison by Major Element (In thousands of 2002 dollars)

Element #	Description	Unit of Measurement	Cost *YESTERDAY*	Cost **TODAY**	"YESTERDAY-TO-TODAY" Cost Trend
1.	Real Estate	Median Home Price	MD: $162; VA: $198; DC: $188	MD: $195; VA: $319; DC: $250	MD: 20%; VA: 61%; DC: 33%
2.	Cut and Cover Station *	Station	86,310	64,640	-25%
3.	At-Grade Station *	Station	24,840	17,220	-31%
4.	Aerial Station*	Station	37,860	30,250	-20%
5.	Parking Structures*	Space	13	9	-28%
6.	Cut & Cover Line *	1,000 Route foot	18,430	13,153	-29%
7.	At-Grade Line *	1,000 Route foot	2,340	1,750	-25%
8.	Aerial Line *	1,000 Route foot	12,500	8,700	-30%
9.	Tunnel Line *	1,000 Route foot	19,373	11,006	-43%
10.	Automatic Train Control	Route-mile	3,640	2,500	-31%
11.	Communications	Station	1,270	930	-27%
12.	Running Track	Route-mile	2,390	1,925	-19%
13.	Trackwork: Double-crossover	Unit	680	620	-9%
14.	Trackwork: Equilateral Turnout	Unit	180	120	-33%
15.	Traction Power	Substation	5,250	2,660	-49%
16.	Elevators	Unit	290	260	-10%
17.	Escalators	Unit	550	475	-14%
18.	Fare Collection	Station	1,020	870	-15%
19.	Rail Cars	Car	2,030	1,900	-6%
20.	Rail Yards	Car Stored	568	405	26%

*(Excl. of line/trackwork/systems)

Conclusions

The tabulation shown on this page compares the actual budgets of two Metrorail extension projects with a "what-if" budget that was developed by applying the full range of cost trends discussed previously. The "what-if" budget reflects the total cost for the project if the cost trends were not realized. Hence, the analysis is intended to represent a "pre-trend" budget, not a future year analysis. To develop the "what-if" budget, the actual cost of each element was increased against the value of its downward trend. For elements exhibiting upward cost trends, (i.e., real estate) a decrease was applied. A composite trend was computed for each element by incorporating systems and trackwork trends where applicable. A mid-point of linear extrapolation of these trends was then estimated. The trends derived as follows:

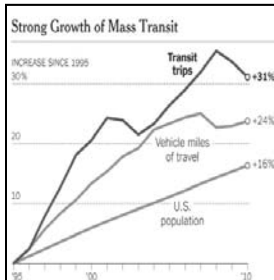
- Line-Trackwork & Systems -30%
- Stations -25%
- Parking Structures -28%
- Railcars - 6%
- Real Estate 35%
- Rail Yards -16%

Figure 8: Metrorail Construction Total Costs Comparison For Two of the Most Recent Extensions (in Year of Expenditure Dollars)

-Actual- Project Budget costs at completion			-What-if- Cost Trends Not Realized		"What-if"-to-Actual Cost Differences	
● Green Line Extension to Branch Ave. $ mil (1)	● Blue Line Extension to Largo (b) $ mil (2)	**Major Budget Line-Items**	● Green Line Extension to Branch Ave. $ mil (3)	● Blue Line Extension to Largo $ mil (4)	● Green Line Extension to Branch Ave. $ mil (3-1)	● Blue Line Extension to Largo $ mil (4-2)
410	265	Line, Trackwork & Systems	530	345	120	80
260	115	Stations	325	145	65	30
40	29	Parking Structures	51	37	11	8
30	32	Railcars	32	34	2	2
50	19	Real Estate	33	12	(18)	(7)
125	0	Rail Yard	145	0	20	0
$915M	$460M	Total Costs	$1,116M	$573M	$201M *22%*	$113M *25%*

Notes:
Green Line Extension: (6.4-mile, 5-station, 31% underground, 23% aerial and 40% at-grade) opened to passenger service 1/13/01; the rail yard opened to revenue service 3/1/03
Blue Line Extension: (3.2-mile, 2-station, 85% underground, 5% aerial and 10% at-grade) opened for passenger on 12/18/04.

The construction phase for the Green Line extension began with the award of the first major construction contract in September 1995 and was completed 65 months later in January 2001. Similarly for the Blue Line extension, construction began in March 2001 was completed in 45 months on December 18, 2004. As shown in the table below, if the cost trends had not been realized, the Green Line extension would have cost $202 million (22%) more than the actual cost. Similarly, the Blue Line Extension to Largo would have cost 25% more, or about $113 million. It should be noted these are based on year of expenditure dollars. Normalization of these costs to a common year could provide for a significant increase in the savings calculated. The difference in "savings" between the two projects may reflect among other factors the limited number of construction contracts, the Design-Build delivery method utilized for the Blue Line Extension to Largo and the continued productivity gains between the mid-90's and the early-00's of the mid-point of construction for these two projects. The 6.5-mile, 5-station Green Line extension was completed via 25 major prime contracts low-bid awarded while the 3.1-mile, 2-station Blue Line extension was completed via only two major design-build/best-value awarded construction contracts.



Source: American Public Transportation Association via the New York Times

It should be emphasized again that the purpose of this analysis is not to establish numerical conclusions; it is only to "check-the-trends" of Metrorail construction costs. Although Metrorail construction trends appear to satisfy the **BFC goal: *Better-Faster-Cheaper***, there is still a lot of work remaining for all stakeholders to make sure costs continue to trend in the right direction, with even steeper slopes, over the next 25 to 30 years. This will be necessary for the taxpayers who pay for these projects to be assured they are getting the ***"most bang for their buck"***. This may support the goal to add another 60 to 70 miles of Metrorail extensions by 2025, as adopted by the WMATA Board of Directors in March 1999, to be realized.

These productivity and cost trends are not the only reasons to be optimistic about the future of the transit industry. Since 1995, growth in transit ridership (31%) has outpaced growth in both U.S. population (16%) and vehicle miles traveled (VMT) (24%). Though the number of transit trips dipped during the recession, it is again on the rise. The analysis in this paper lends support to the conclusion that the rail transit construction industry is substantially increasing productivity and lowering costs, building the case for continued expansion of such facilities to meet growing demand.

Disclaimer:
This is a summary complied for this conference from similar papers previously presented by the author at several professional gatherings. This presentation is an abstract of a 2-year in-depth study, based on the 30-year development of the Washington Metro Rail System (WMATA) where the author was the Executive Manager for nine years, in charge of engineering and construction. Concepts, methodologies, data, figures, findings and conclusions included in this presentation are not by any means and forms the responsibility of my previous (WMATA) and present (Parsons) employers. Responsibility for errors and omissions lies solely with the author.

BRING PEOPLE TO WORK:
A SUSTAINING FUNCTION OF COMMUTER RAIL SERVICES

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ABSTRACT:

Evidenced by the services provided to travelers for almost a century, commuter rail proved that it not only played significant roles in reducing congestion but also a sustainable mode in providing safe, reliable and high qualify option for commuters. Recent travel behavior changes show that the share of commuting trips during the peak periods are declining while recreational, social, and personal trips during non-peak and weekends are rising.

This manuscript records an effort to explore viable ways for a traditional commuter rail, Atlantic City Rail, serve current travel market. After a brief review of the historical development, the authors have focused on temporal distribution of travel demands along the ACRL corridor. Responding to the demands of patrons, a schedule optimization was developed and partially implemented for the service.

1. INTRODUCTION

Congestion on highways and urban streets in a large number of America cities has stimulated people to renew commuter rail services, which have existed and served commuters since the early part of the last century. According to Metro (2010), commuter rail is an electric or diesel-propelled suburban passenger train service consisting of local short-distance travel operations between a city center and adjacent suburbs. Commuter rail does not include intercity passenger travel. commuter rail operations generally use existing or former freight railroad right-of-way and combined freight use (Sun, 2004).

The inherited commuter rail systems in the United States present challenges to serve the new travel paradigm: dispersed origins and destinations, less peak hour commuting trips, more non-working, off peak travel. The train schedule have been tweaked around throughout the decades to fit various infrastructure, capacity, station, and crew requirement but rarely deviated from the concentration of peak period services.

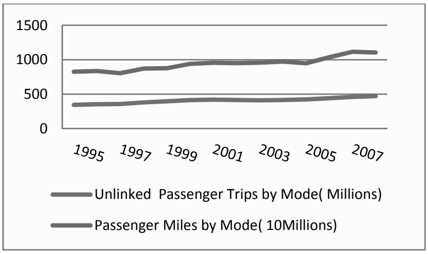
In their effort to assist New Jersey Transit (NJ Transit), the authors have conducted a comprehensive evaluation of the Atlantic City Rail (ACR) Operations. Based on their in-depth research on weekend, non-commuting and non-peak travel and results of ridership survey conducted along the ACR Line, the authors have performed systematic analysis of temporal and spatial distributions of travel demand. Limited by the length of the manuscript, only temporal distributions and schedule modifications are presented here

2. THE NEW TRAVEL PARDIGM

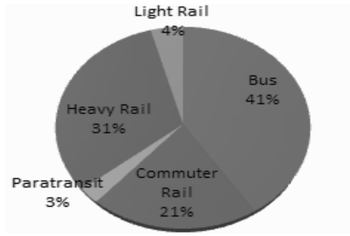
Recent travel data have revealed that off peak travel, especially on weekends, can often exceed weekday, peak hour volume, thereby creating unanticipated congestion. Fewer people are commuting to work, but the overall trip volume, travel length, and destination points are on the rise, largely because of increased leisure, recreational, or other non-working trips.

Referring to the APTA commuter rail definition, commuter rail refers to passenger trains operated on main rail line to carry riders to and from work in city centers. The trains are normally made up of a locomotive and a number of passenger coaches. The length for commuter rail used to range from 10 miles to 50 miles. In some situation, it only operated in rush hour. In other cities, operation will be covered throughout day and night and even on weekends. Service rarely is offered more frequently than one train every 30 minutes and station spacing is typically measured in miles.

As shown in Figure 1A, the commuter rail ridership, measured by “Unlinked passenger trips by mode” and “passenger miles by mode”, has experienced steady increases between 1995 and 2008. The recent economic down turns have reduced travel along all the modes, but the general share of rail transit remain steady (APTA, 2010), as shown in Figure 1B. Given the long history and wide spread coverage of commuter rail, it is necessary to explore viable ways to adapt to the new travel paradigm.



A. Historical Commuter Rail Ridership



B. Mode share for Commuter Rail

Figure 1. Commuter Rail Ridership Trends

Source: APTA, 2010.

3. ATLANTIC CITY RAIL LINE

The Atlantic City Rail Line (ACRL) is a commuter rail service operated by New Jersey Transit (NJT) between Philadelphia, Pennsylvania and Atlantic City, New Jersey. The Atlantic City Rail Line connects Philadelphia and Atlantic City via six other stations, which include Cherry Hill, Lindenwold, Atco, Hammonton, Egg Harbor City, and Absecon. It takes approximately 90 minutes to traverse the entire route of around 60 miles (NJ Transit, 2010).

The current Atlantic City Rail Line was initiated by New Jersey Transit (NJ Transit) in 1990 to serve commuters as well as casino travelers between Atlantic City and Lindenwold, NJ. At the Lindenwold station, passengers had to transfer to PATCO in order to journey to Philadelphia and beyond. NJT eventually extended service into Philadelphia via Amtrak's 30th Street Station and a new station facility was built in Cherry Hill, NJ. Besides extending service route, adding fueling facilities, and cutting cost of operations, NJ Transit also worked with the Atlantic City Jitney Owners Association (ACJOA) to provide shuttle services between the Atlantic City Rail Terminal and the city's casinos and boardwalks (Railway Age, 1998). The service hours range from 4:30 AM departing Atlantic City to 3:20 AM turning in at the 30th Street Station in Philadelphia. With only one hour gap between services, ACRL almost qualifies for a 24/7 service even the trains are far between.

4. TEMPORAL DISTRIBUTION OF TRAVEL DEMAND

New Jersey Transit has collected ridership data via ticket sale information since their initial operation of ACRL in 1990. As shown in Figure 3, the annual ridership along ACRL experienced steady growth during the 1990s. The growth rate in the early 1990s reached double digit. Ridership around the millennium, from 1999 through 2003, was fairly stable with minor decreases, such as year 2001. Ridership growth along the ACRL is obvious since 2004 and maintained pace until now, the early part of 2010. The growth rate is measured around five percent per year, ranging from negative two percent to a positive 17 percent not counting the first year of operations.

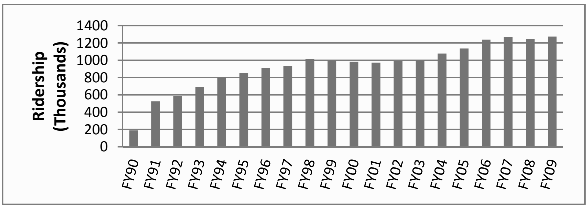


Figure 3. Annual Ridership along ACRL

Source: New Jersey Transit, 2010.

Defined by the unique characteristics of Atlantic City Casinos, working shifts of casino and service employees and behavior of casino patrons, the travel demand or patterns along Atlantic City Rail is very different from other commuter rail services.

4.1 Weekday versus Weekend:

As one of the major terminals along the ACRL route, Atlantic City with a large number of casinos and famous board walk has been expected to attract a higher share of non-commuting trips, so was ACRL. Other research (Liu, 2009; PBQD 2005) shown that total number of trips on weekends in general is about 80 percent of that on weekdays, the data observed in ACRL shown that weekend travel is much higher, averaging 118 percent for Saturday and 96 percent for Sunday as demonstrated in Figure 4.

The overall weekend ridership still peaks consistently during the summer season. The Figure 4 depicts the average weekday ridership for each month (blue), actual ridership for specific Saturday (Red) and Sunday (Green) of each week. The combined bar chart not only shows the absolute ridership volumes for that particular week but also indicates the relative ratios of weekday versus Saturday and Sunday as measured by height of each bar. Some unusually high weekend ridership have been observed in a few selected periods, such as February, March, and May, which lead our search into certain special events.

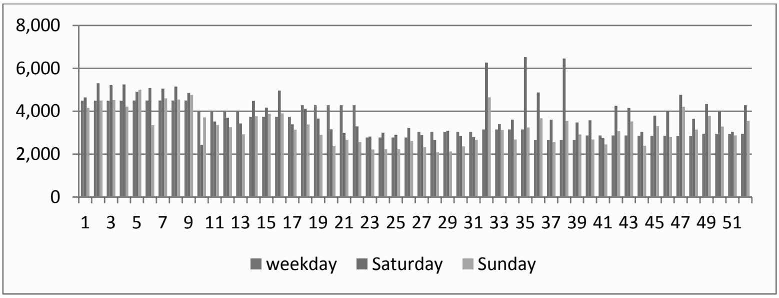


Figure 4. Ridership Distribution: Weekday versus Weekend
FY 2009: July 2008 – June 2009.

4.2 Unique Daily Distributions

The unique travel patterns of ACRL riders are characterized by the concentrated peaks around the noon and later evening hours, which is different from regular commuting trips. As shown in Figure 5, the common morning peak hour that is usually observed in other cities is not obvious here along the ACRL. Conversely, the heavy volume that is mostly affected by the shifts of casino resorts, hotels and restaurants normally arrives around noon and the early afternoon, such as from 4:00 to 5:00 PM. Since the survey is ended at 8:00 PM, it may not have captured the entire shift patterns.

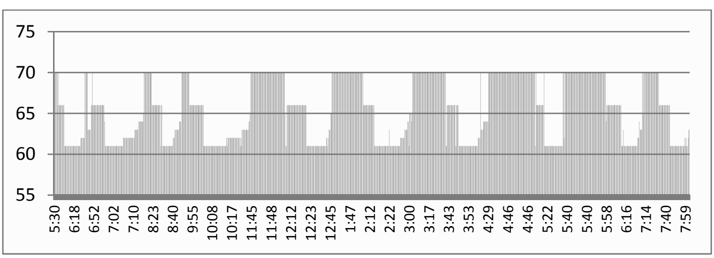
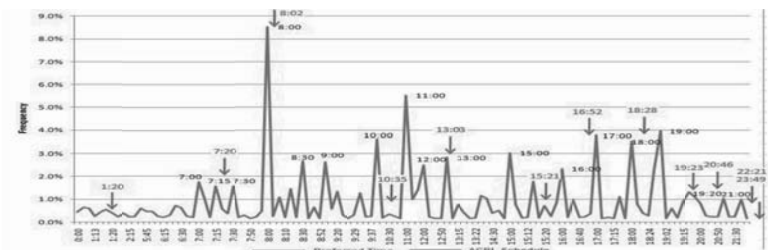


Figure 5. Daily Distribution of Boarding Volumes

When asked about the preferred departure and arrival times, passengers provided their preferences, which are somewhat different from what they are currently travelling or the services allow. To understand the overall time of the day demands from/to the Atlantic City Station, the research team superimposed AC rail schedule onto the combined preferences of both commuting and recreational trips for departure and arrival times. As shown in Figure 6A, the existing rail schedule does cover a number of preferred arrival peaks, such as the 8:02 arrival may satisfy the demand for 8 AM arrival and 4:52 PM train for 5 PM preferences while some of the large demand, such as 9 AM arrival was not served at all. Besides the general preference schedule, particular capacity and level of service may warrant further investigation.

Figure 6B depicts the distribution of preferred departure times vs. existing operation schedule. Similarly, some scheduled trains serve the preferred departure time perfectly such as 4:35 AM, 4:42 PM, 5:52 PM while others need some adjustment. For example, one of the larger preferred time slots fell at 45 minute after mid-night; the earliest train that may serve this demand is scheduled at 1:45 AM. Waiting for an entire hour, especially during that time of the day, may prevent a large portion of people from using the ACRL service all together. Some services may only need minor adjust to shorten the waiting time, therefore improve level of service and passenger perceptions. For example, trains departing ACR station at 1:45 AM, 6:44 AM, 2:46 PM, and 9:46 PM all lags the preferred time more than 45 or 46 minutes without serving additional demand. If no other constraints, moving these trains half hour earlier may shorten the total waiting time at ACR station significantly; this will in turn improve the level of service and may also have the potential to attract additional riders.



A. Preferred & Scheduled departure times

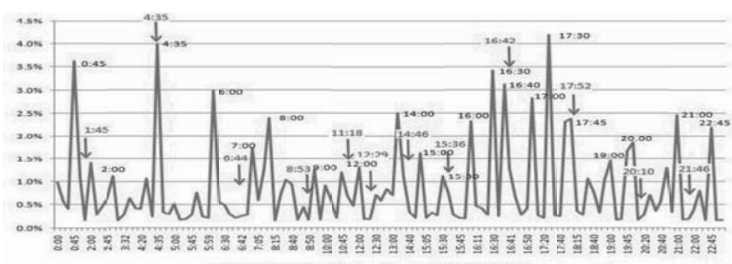


Figure 6. Differences between Scheduled and Preferred

5. OPTIMIZING OPERATIONS

Based on the survey responses and travel demand estimate, the study team has evaluated a range of creative operating and infrastructure improvement solutions and quantified associated benefits in terms of service levels, travel time and line capacity. Using operation analysis software, the authors have performed network simulation and run time simulation for various modifications to the existing infrastructure, capacity, and schedule. Relevant to the subject of this manuscript, the improved schedule is shown in Figure 7.

Supported by NJ TRANSIT staff, the research team focused on Friday operations when both commuter and ACES, a weekend only service between Manhattan and Atlantic City, services operate. Brief companion evaluations of Saturday and Sunday operations were also conducted to ensure the proposed schedule changes can be accommodated by the infrastructure and operating plan scenarios.

6. SUMMARY

As shown in this project experience, a simple exercise of operation analysis corresponding to the temporal distributions of travel demand along a particular corridor may improve the overall efficiency of the service without any major investment in infrastructure. All agencies tweak or modify their schedule but not many document the reasons or exam the ridership demand as many old timers have the mindset of a typical commuter rail services from decades ago. Along with the emerging travel behavior changes, it is time for commuter rail agencies to adapt their service to the demand patterns of the travelers to cultivate or capture the largest mode share potentials.

Figure 7. Atlantic City Rail Line Schedule.

Source: NJ Transit, 2011.

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Opportunities and Operational Difficulties of Introducing Bus Rapid Transit (BRT) in Dhaka

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ABSTRACT

Dhaka is one of the most densely populated cities in the world. The abrupt increase in population along with diverse urban land use patterns has engendered an ample travel demand. In addition, gradual deterioration of level of service of public transport system and increasing private car ownership create acute intolerable congestion. In these circumstances, Bus Rapid Transit (BRT) is one of the most effective short term solutions because of its high capacity as well as relatively low construction and operating cost. Despite the high opportunities of introducing BRT in Dhaka, it will face some operational difficulties such as high occupancy, high operational fleet size, small headway, priority in intersection and signal control, etc. Result shows that to satisfy the projected high passenger demand, the headway will be 16 seconds and operational fleet size; occupancy will be very high in many locations, which will make the BRT operation difficult and ineffective.

1. INTRODUCTION

Dhaka city, the capital city and power center of Bangladesh, is suffering from congestion in every working day from dawn to dusk and even after that. At present 15 million people live in an area of 1528 km^2 and by 2020, it is expected to raise the population up to 20 million. From various study it was found that about 21 million trips generate everyday within the city and 94% of these demand are dependent directly or indirectly on public transport (JICA, 2010). However, due to chronic congestion throughout the city and inefficient operation policy, existing public transport system has failed to provide complete service up to passengers' expectation. To address and solve these problems of public transportation in Dhaka city, government has undertaken a project named Strategic Transport Plan (STP). As a measure of solution, STP suggests Bus Rapid Transit (BRT) system along three major routes of Dhaka city (Louis Berger Group and BCL, 2005). Among these three routes, the route from Uttara to Ramna (BRT-3) and its operational policy is the matter of concern of this research paper.

Considering the urban population density pressure and several constraints facing nowadays the mobility in Dhaka, the local authorities have realized the necessity of implementing improved public transport system, BRT. Better service and well managed BRT operation can make it an attractive urban transport mode and eventually caused decreasing use of private vehicles as trip makers will prefer to use BRT. In this regard, the design of BRT, particularly operational design, should be comprehensive and strategic considering the local constraints and peculiarity.

The main objective of this paper is to determine the key issues and operational difficulties towards implementing BRT-3 in Dhaka. This conceptual approach will give an overview of the operational characteristics which must be taken into account before implementation. Developing countries as well as cities having high passenger demand, like Dhaka, can get an overview of the issues and operational difficulties which must be considered while implementing BRT.

2. SYNOPSIS OF BUS RAPID TRANSIT SYSTEM (BRT)

The fastest growing urban population created a surge of demand and great pressure on public transport infrastructure. Bus Rapid Transit (BRT) has been found to be one of the most cost effective mechanisms for cities to rapidly develop a public transport system that can achieve a full network as well as deliver a rapid and high quality service. The attraction of BRT to policy makers is that it has potential to be cost effective than similar rail based public transport system (Wright & Hook, 2007). Again, compared to conventional bus service, BRT provide high speed and high capacity service through shorter boarding time and faster alighting of passengers, off board fare collection and fare verification, multiple stopping bays at stations, flexible use of buses with multiple doorways, platform level boarding and optimum station platform (Fjellstrom & Xiaomei, 2009). Vehicle is an important element as it provides a visual perception of BRT system's quality and service toward customers. It also has strong impact on measurable system performance, in terms of – speed, reliability and cost (Zimmerman & Levinson, 2004). Vehicle should be selected and designed to support anticipated passenger and to provide on board comfort. Different types of vehicle ranging from 40 to 45 feet for single unit to 60 to 82 feel for articulated or bi-articulate vehicle can be considered. Another important aspect of vehicle selection is vehicle technology. Environment friendly technology like-compressed natural gas (CNG), hybrid electric bus etc. should be considered for BRT system. However, vehicle should be well proven in revenue service before being introduced into BRT operation (Candia, 2007). Bus delays at traffic signal account for 10% to 20% of overall bus travel times and 50% or more of all delays (Levinson et al., 2004). Therefore, special measure is warranted in order to reduce delay and provide customers a more dependable service through greater schedule adherence, reduced travel times and more comfortable ride. Traffic signal control at intersection for BRT includes passive, active and real time bus priorities as well as pre-emption. Different types of signal priorities are used in different cities based on service frequency, side street queue, BRT bus bunching etc. However, very frequent BRT service can increase the travel time by bunching of buses and eventually creating congestion at station. Again, at intersection, it can create long queue in side streets which create a negative perception about BRT. In such cases, more costly and time consuming alternative like- grade separated intersection can be provided to reduce travel time and serve one of the main purpose, reliability, of BRT service.

BRT required providing highest capacity and safety for its operation. But improving safety often leads to less efficient system. In this regard, integration of Intelligent Transportation Systems (ITS) in BRT service will provide system managers, passengers and drivers with smooth and safer flow of BRT buses with better tool for controlling flow and ensuring better safety for both passengers and vehicles. ITS have both direct and indirect benefits. The direct benefit anticipated from actively managed ITS road applications are reduced delay, increased throughput, smoother flow, fewer crashes and quicker response time. Secondary benefits may include consistency, reliability of travel time, increased passenger confidence; these eventually help to increase system efficiency.

Fares provide the signals to the market regarding resource allocation and allow the financial sustainability of operations. In order to bring flexibility and increased operational efficiency several fare scheme can be operated in BRT simultaneously, such as; flat fare, zone fare, discounted fare etc. Based on trip frequency of user various type of media fare policy (i.e. single trip ticket, multiple trip ticket, temporary ticket) can be introduced. The process and physical location of fare collection and fare verification can either be on-board or off-board based on relative boarding alighting time, queue waiting time etc. In recent days, electronic vending machine and smart cards are extensively used as fare transaction and verification media. Electronic vending machines distribute and verify fares directly to users. However, smart cards expand the options for customized fare system as well as keep the transaction easy and simple (Spielberg, 2004). Again, smart card permits a wide range of travel data to be collected on individual customer movements, which eventually assist in system development and revenue distribution (Wright & Hook, 2007).

The operational design of BRT should be undertaken to ensure frequent, direct, easy to understand, reliable, safe and above all, rapid service. In this regard, closed BRT system operating for 16 hour each day with midday headways of 15minutes of less and peak headways of 10 minutes or less can be introduced. Considering the high demand in Dhaka, conventional CNG operated articulated bus should be the choice of transportation vehicle as it can carry about 160 passengers in each bus. Another major concern would be intersection and signal control. To ensure continuity of frequent and rapid BRT service, grade separated intersection would be the appropriate choice for Dhaka city. Modern smart card based fare system can be introduced as it can be used in various purpose. Though all these measures have individual advantage and application, they cannot be effective and useful in BRT operation in Dhaka city without their collective action. Therefore, these elements must be integrated into a system that optimally serves Dhaka city within certain physical constraints and difference of each corridor.

3. CURRENT TRANSPORTATION SYSTEM OF DHAKA

Dhaka is one of the most densely populated cities in the world. It is perhaps the only city in the world without any well and properly planned mass transit system. In general, rapid growth, low incomes, and extreme inequality are among the fundamental reasons of transport problems in Dhaka, similar to every other megacity of developing countries (Pucher et al., 2005). In an ideal city, 25% of the surface area should be used for constructing roads and lanes, but Dhaka has only 8% (DCC, 2002). Moreover, like most of the developing cities, Dhaka's road network hierarchy is poorly defined, with very limited number of arterial and main roads. The prevailing situation is even worse when taken into account the fact that, this inadequate road space is shared by both motorized and non-motorized traffic (heterogeneous traffic mix) and vehicles with varying characteristics (e.g. three-wheelers, human haulers, pickups, vans etc.). Some striking features found from the survey can be acknowledged as:

- Buses comprise 9.7% of the vehicle mix that combines all vehicles and pedestrians;
- Rickshaws and vans comprise 28.4% of all vehicles;
- Auto-rickshaws (with 36.8%) and Cars/Light Vehicles (with 43%) comprise a substantial proportion of all motorized vehicles (2-stroke three wheelers);
- Whereas buses comprise a small proportion (9.7%) of the mix, bus passengers account for 77% of all people.

The rapid urbanization process, poor transportation facilities and policies, varied traffic mix with over concentration of non-motorized vehicles, absence of dependable public transport system and inadequate traffic management practices have created a situation where cars and motorcycles are becoming increasingly necessity for the middle class, to get around in the metropolitan Dhaka (Hoque et al., 2012). As a result, further congesting the roads and worsening air pollution, noise, and safety problems. The number of registered motorized vehicle stands at 7, 08,197 in June, 2012 increasing from 3, 03,215 in 2003 (more than 200% increase in less than 9 years). More than 40% of all registered vehicles are in Dhaka (total 17, 51,834 in Bangladesh) (BRTA, 2012).

The following table (Table 1) shows modal distribution (in terms of trips) by income groups. From the table, it is clear that the low income group is responsible for the lion's share of trips on foot (73%) while most of the rickshaw trips are made by the middle income group (59%) (JICA, 2010). These two income groups are also main users of available transit services in Dhaka, which is a very promising sign. The significance of walk, rickshaw and transit trips is obvious as they cater for 97% of the city dwellers.

Table 1: Modal Share of Trips With Respect to Income Groups

Income Group	Proportion of Income Groups (%)	Modal Share			
		Walk	Rickshaw	Transit	Motorized (non-transit)
Low (<12,500)	48	73	38	41	14
Medium (12,500-55,000)	49	26	59	56	66
High (>55,000)	3	1	3	3	20
Total	**100**	**100**	**100**	**100**	**100**

The alarming trend which can be spotted from the Figure 1 that, while the total number of buses remain almost same in this 9 year period, private vehicles, particularly, number of cars and motorcycles more than doubled. Public transport such as buses and minibuses has grown at a very insignificant rate even though the demand for public transport services has increased noticeably. On the contrary, Motorcycles, cars and jeeps/ station wagons constitute around 42%, 25% and 10% of total motorized vehicles respectively (BRTA, 2012).

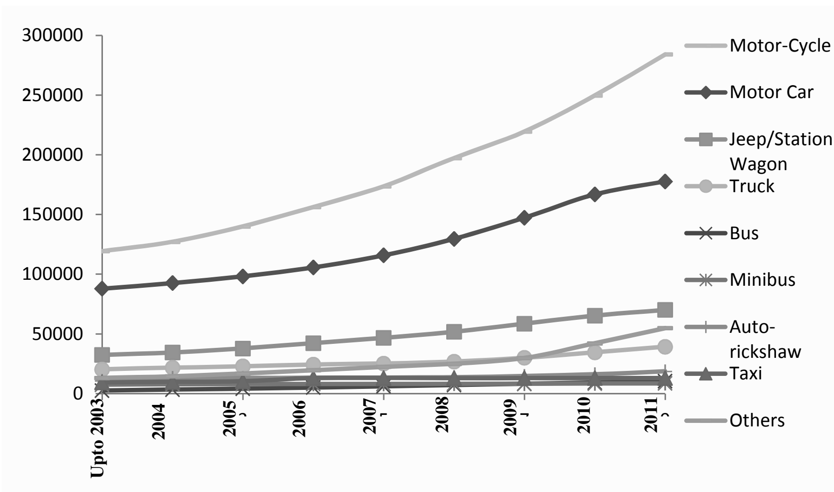

Figure 1: Motorized vehicle growing trend in Dhaka

4. BUS RAPID TRANSIT (BRT) IN DHAKA

To improve the current situation and reorganize the existing traffic system methodically, the government prepared the Strategic Transport Plan (STP) for Dhaka which recommended various types of development agenda, such as three Bus Rapid Transit (BRT) routes, three Mass Rapid Transit (MRT) (Metrorail) routes, 50 highway projects etc. It suggested the development of six major corridors as mass transit routes as a means for achieving sustainable urban transport in the city. Three radial corridors are thought to be potentially suitable for Bus Rapid Transit (BRT). They are known as line-1, line-2 and line-3 (Louis Berger Group and BCL, 2005). Among these three BRT corridors, the corridor from Uttara to Ramna (BRT line-3) is the matter of concern of this research paper. Route map of line-3 is provided in the appendix.

5. ANALYSIS OF OPERATIONAL CHARACTERISTICS

5.1 Data Description:

In order to estimate the BRT demand, a field traffic survey was carried out by DevConsultants Limited in 2009. This survey was conducted on a weekday, using recorded video representing 16 hours (6AM - 10PM) of traffic flow in a day. 160 hours of traffic flow has been recorded by 10 cameras for BRT line-3. From the survey result, it can be observed that majority of the passengers (about 60% to 80%) was carried by buses as NMT was banned for this BRT route; but in places where personalized paratransit had accessibility, i.e. auto rickshaws was commonly available, bus share of passengers was slightly less. To find out the operational characteristics of the BRT line-3, peak hour demand was projected to 2013 and 2020. It is considered that the existing buses and para transits are not allowed to operate on the route after opening the BRT. Consequently, all the buses and para-transit passengers will be compelled to shift to BRT. As the non BRT mixed traffic lanes will be free from bus and other para-transit services, it will increase the speed of cars. Due to increase of speed of car, there will be only little modal shifting from the private car to BRT. However, 5% of modal shift from car to BRT is considered under normal pricing policy. In addition, as passengers will be attracted by new BRT service, there will be 7% annual growth rate (close to expected GDP growth rate) in demand over the year 2013. Later, until the year 2020, it is assumed that the annual growth rate will be reduced to 3% (Devcon 2009). Peak hour BRT passengers' demand estimated for different segment for 2013 and 2020 (to city and from city) is illustrated in Table 2. As the BRT line-1 and BRT line-3 will share the same station, it is noticeable that the demand at Azampur and Khilkhet is very high considering the other location. BRT line-1 and Line-3 will split at Kuril. The peak hour demand will be less at Moghbazar and Tezgaon with respect to other location.

Table 2 Peak Hour BRT Demand for 2013 and 2020

Location	Year	To City				From City			
		Mean	Standard Deviation	Min	Max	Mean	Standard Deviation	Min	Max
Azampur	2013	13059	5955	7907	25918	12474	5203	7894	22721
	2020	16061	7324	9724	31876	15342	6177	9708	27944
Khilkhet	2013	17018	7861	9181	34369	17058	5764	11007	27658
	2020	20930	9668	11291	42270	20979	7089	13537	34016
Kakoli	2013	13067	7366	6225	29438	13149	5133	7470	21799
	2020	16071	9059	7656	36205	16172	6313	9187	26809
Mohakhali	2013	8747	4776	3314	23002	10026	5503	2733	25882
	2020	10758	5873	4075	28289	12330	6768	3361	31831
BG Press	2013	5565	3915	1350	13413	5178	3272	2156	12956
	2020	6844	4814	1660	16497	6369	4025	2652	15934
Moghbazar	2013	6757	2999	3559	13476	979	808	0	2616
	2020	8311	3688	4377	16574	1204	994	0	3218

5.2 Operational Characteristics:

Operational characteristics such as system capacity, occupancy per BRT bus, operational fleet size, headway, dwell time, signal control coordination, etc. play a vital role towards successful implementation of BRT. Based on the projected peak hour demand different operational characteristics have been determined (Ceser et.al., 2007).

5.2.1 Vehicle Capacity/ Occupancy per Vehicle:

Vehicle capacity/ occupancy per vehicle can be determined using following equation.

$$Occupancy\ per\ vehicle, C_b = \frac{C_0}{[\,L_f \ast F \ast N_{sb}]} \dots\dots\dots (1)$$

Where, C_0 is the demand (pphpd), L_f is the load factor which is the percentage of a vehicles total capacity that is actually occupied, F is the service frequency (veh/hour) and N_{sb} is the number of stopping bays. It is assumed that average peak hour bus frequency will be 120 BRT buses per hour. From the eq. (1) it is clear that, if the frequency is less, the occupancy will be high as the passenger queue will tend to increase. Based on the peak hour demand, using eq. (1), the occupancy per vehicle at different station location, from Azampur to Moghbazar has been determined which are tabulated in Table 3.

5.2.2 Headway and Dwell Time:

Headway is the time difference between two consecutive bus. As the peak hour demand is very high, the headway will be very small. Headway depends on the demand and vehicle capacity. Procurement of larger bus will reduce the required number of buses. Conversely, smaller bus will contribute higher frequency services and thus shorter customer waiting times. Regardless by which bus will be selected in the context of frequency, the main objective is to satisfy the forecasted demand. 160 passengers carrying capacity articulated bus has been chosen as design vehicle. Headway can be determined using following equation.

$$Headway, h_{min} = 60 \ast \frac{C_b}{C_0} \dots\dots\dots (2)$$

where, C_b is the total vehicle capacity (passenger/ vehicle) and C_0 is the peak hour demand. For the peak hour demand, in 2020 at Kakoli, will be 36205 pphpd and the headway will be 16 seconds, which is too small and obviously will face severe operational difficulties. On the other hand, the dwell time is the amount of time that any vehicle is occupying a given stopping bay. It consists of three separate delays: boarding time, alighting time, and dead time. Dwell time can be determined by following equation.

$$Dwell\ Time, T_d = T_a + \frac{1}{6} \ast L \dots\dots\dots (3)$$

Where, T_a is the average time for pulling in and out of bay which is 10 seconds and L is length of the articulated bus which 18.5 m. So, the dwell time is 13.083 seconds. In addition to that, the boarding and alighting time will be added to this dwell time.

5.2.3 Operational Fleet Size:

Based on the demand and vehicle capacity, the operational fleet size or required number of vehicle can be determined. Fleet size is very important to determine the total number of vehicle needed in each direction in a certain period of time, to satisfy the certain demand on that particular hour. It can be determined using the following equations.

$$Operational\ Fleet\ Size, F_0 = D_0 \ast \frac{T_c}{C_b} \dots\dots (4)$$

Where, D_0 is the demand on critical link (pphpd), T_c is the travel time for a complete cycle (hour) and C_b is the vehicle capacity (passenger/ vehicle).

$$Total\ Fleet\ Size, F_t = F_0 + F_0 \ast C_v \dots\dots\dots (5)$$

Where, C_v is the contingency value (10% assumed). For the whole route with a length of 18.5 Km, average velocity of 40 km/h and minimum terminal time 7.5 min, the total cycle time will be 70.5 min (1.175 hour). Using this information, total peak hour fleet sizes are determined which are tabulated in Table 3. 16 hours fleet size distributions at different station location are illustrated at Figure 2.

Table 3: Occupancy per Vehicle and Fleet Size at Different Station Locations

Location/ Year	Occupancy				Fleet Size			
	To City		From City		To City		From City	
	2013	2020	2013	2020	2013	2020	2013	2020
Azampur	127	156	111	137	205	252	180	221
Khilkhet	168	207	136	167	272	334	219	269
Kakoli	144	177	107	131	233	286	172	212
Mohakhali	113	139	127	156	182	224	205	252
BG Press	66	81	64	78	106	130	102	126
Moghbazar	66	81	13	16	107	131	21	25

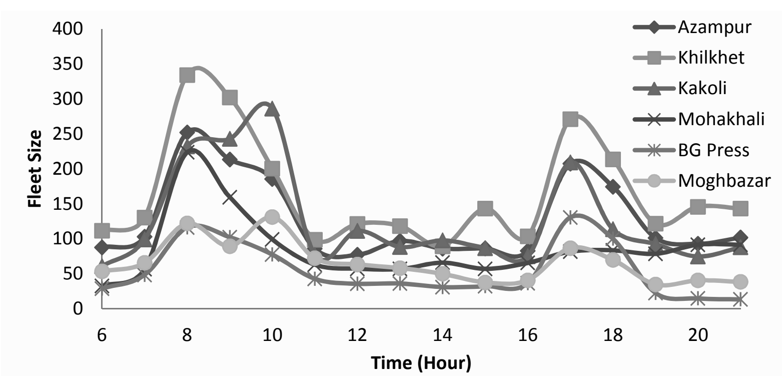

Figure 2: Fleet Size for Different Station Location From 6AM -10PM

6. RESULTS AND DISCUSSION

Results indicate that the peak hour occupancy at Azampur, Khilkhet, Kakoli and Mohakhali is very high, even more than the capacity (160 passengers) of the design vehicle. In 2013, at Khilkhet station the occupancy is 168 and in 2020 it will become 207 (to city) Furthermore, at Kakoli the forecasted occupancy is 177 , which is greater than the vehicle capacity. So it won't be possible to cater this high peak hour demand with this BRT system and obviously this system will face operational difficulties. However, in off peak hour, BRT can satisfy the demand. Analysis shows that, to satisfy the peak hour demand, the headway will be 16 seconds (will vary with respect to demand). This headway is very small, and very hard to maintain in real time. In addition, low headway will create problem to control signal at the intersection. If the signal priority is given to BRT than there will be acute congestion in non BRT lane and it is perceptibly not feasible to give priority with such a low headway. The dwell time will also vary based on the demand, boarding and alighting delay. During the peak hour it will be very high and greater than the headway, as a result, at the station, there will be a queue of the BRT buses which will create congestion in the BRT lane. Fleet size represents that, in 2013, each direction more than 250 buses and in 2020 more than 300 buses will have to operate to satisfy the peak hour demand. This will be very much critical to operate maintaing a very small headway. On the other hand, it will create adverse effect on the intersection creating acute congestion. However, in off peak hour the occupancy will be less so as the fleet size (Figure 2). From the results, it is understandable that high peak hour demand is the major hindrance towards effective implementation and operation of BRT. If the demand can be distributed to other public transport mode, headway will become high and dwell time, occupancy, fleet size will become less. Consequently, BRT will perhaps operate smoothly. BRT-1 and MRT -4 can play a vital role in terms of modal share and reducing the demand on BRT-3. However, implementation of MRT is a long term solution and take time to construct. So, it's high time to introduce BRT-3 considering other potential alternative modes and ponder over the matter before it is too late.

The results presented in this paper are based on the data set of screen line survey and conceptual design. Further research with origin destination survey datasets is required to confirm the paper's findings. The work in this paper could be extended to determine the operational difficulties of other alternatives, e.g., BRT-1 and MRT-4.

7. CONCLUSION

Due to increase of private car ownership, the roads are becoming congested day by day in Dhaka. Without modal shifting, from private car to public transport, the condition will become worst in near future. Though the public transport is not well developed, the demand of public transport is very high. For proper modal shifting, it is high time to introduce public transport ensuring reliability, accessibility, comfort, safety and economic viability. In these context, BRT is one of the feasible short term solution due to its low construction and operating cost. But operational difficulties such as high fleet size, high occupancy, low headway with high dwell time, will be the probable hindrance towards implementation of successful BRT. However, BRT can serve effectively in present year, but within 2020, it won't be able to support the ever increasing demand. Alternative solution and other public transport alternatives should be considered besides BRT. So transport planners and decision maker should ponder over the matter and take necessary steps, considering the issues that summarizes in this paper, to develop an effective public transport system for Dhaka.

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APPENDIX

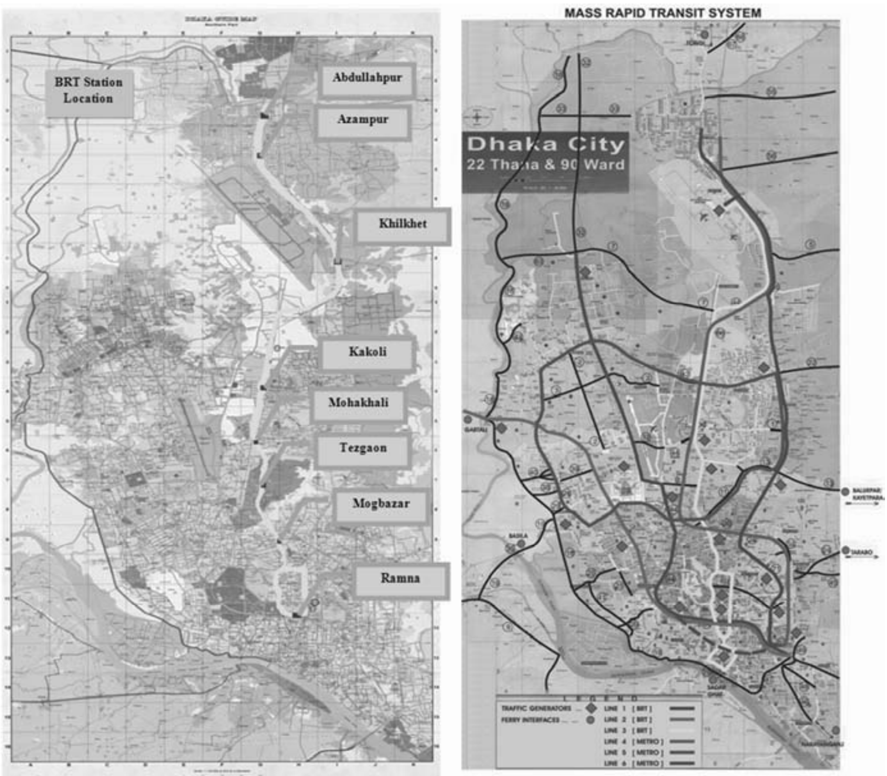

Figure A1: Route Map of the BRT line 3 (yellow line) (left) and STP Suggested Route for BRT and MRT (right)

Modal Integration for Improving Urban Mobility in Dhaka

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1. ABSTRACT

About 15 million people live in Dhaka, the capital city of Bangladesh, with a growth rate of 1.8% which creates huge travel demand as well as numerous transport problems. Lack of effective public transport system and door to door service influence the augmentation of private cars which is causing congestion and deterioration of environment. Though railway is very popular, safe and cheap transport system of Bangladesh but in absence of proper initiatives and investments, the railway could not play the much expected role in the Dhaka's public transport system. However, Dhaka is surrounded by four rivers providing an inbuilt facility for operation of circular waterways, due to financial constrain and lack of appropriate planning for inter connectivity amongst other modes, it's not serving effectively. The airport is in the northern part of Dhaka which does not have any integration with the public transport system, railway stations and waterway terminal. Through the development of public transport system using Mass Rapid Transit, Bus Rapid Transit, commuter rail service along with proper integration of airway and circular waterway, an effective sustainable integrated transport system can be achieved in Dhaka. In this paper an attempt has been made to develop an effective integrated transport system by integrating and improving systematic, effective, and safe operation of all modes. Besides these, the present scenario of transportation system of Dhaka city has been illustrated in the context of transport demand and supply and also discuss about the potential initiatives which will lead to a sustainable integrated transportation system.

2. INTRODUCTION

Bangladesh is a small country having a huge population of 142.3 million people with 964 inhabitants per square kilometers. About 15 million people live in Dhaka, the capital city of Bangladesh, with a growth rate of 1.8% which creates huge travel demand as well as copious transport problems. Due to rapid unplanned development, versatile land use, rapid population growth, poor public transport system and increase of private car users, traffic problems in Dhaka city is becoming very severe day by day. If the unhindered growth rate trends continue, in 2030 more than twenty million of people will live in this small city. On the other hand several flyovers and expressways with no interrelationship among them will turn it into a vulnerable city on the planet. Besides that present fragile transportation system will not be able to cater that massive transport demand.

At present public transport system in Dhaka city consists of conventional bus services, para-transits, taxis, rickshaws and minibuses. A latest survey shows that modal share by rickshaw (13.3%), bus (10.3%), auto-rickshaw (5.8%), car (4%) and walking which is the predominant mode with a share of 62 percent of total trips. Lack of effective public transport system and door to door service influence the augmentation of private cars and other modal shifting which causing congestion and deterioration of environment. Though railway is very popular, safe and cheap transport system of Bangladesh but in absence of proper initiatives and investment in the urban corridor, the railway could not play the much expected role in the Dhaka's public transport system. The rail networks are in the middle of the city with lots of level crossing which creates enormous congestion. If such rail networks can be used as a commuter service with proper planning and treatment in level crossing that will alleviate the public transport demand. Dhaka is surrounded by four rivers namely Buriganga, Turag, Balu and the Sitalakhaya. As a city, Dhaka started to develop from the northern bank of the Buriganga from the place known as Sadarghat since the ancient times. Though Dhaka is surrounded by four rivers providing an inbuilt facility for operation of circular waterways, due to financial constrain and lack of appropriate planning for inter connectivity amongst other modes, it's not serving effectively. The creation of effectual circular waterway will relieve the city's commuters. The location of the airport is in the northern part of Dhaka. But there is no integration along with the public transport system, railway stations and waterway terminal which is situated at the southern part. Through the development of public transport system using Mass Rapid Transit and Bus Rapid Transit, commuter rail service along with proper integration of airway and circular waterway around Dhaka, an effective sustainable integrated transport system can be achieved.

In this paper an attempt has been made to develop an effective integrated transport system by integrating and improving systematic, effective, and safe operation of all modes (roadways, airways, railways and waterways). Besides these, present scenario of transportation system of Dhaka city has been illustrated in the context of transport demand and supply and also discuss about the potential initiatives that will lead to the sustainable integrated transportation system.

3. INTEGRATED TRANSPORTATION SYSTEM

In metropolitan cities of developing countries generally the unplanned public transport (e.g. bus, minibus etc.) compete among them and with other modes rather than complementing. This unhealthy competition leads to duplication of services in many areas and hence proves to be uneconomical. The expected efficiency level of public transport system is hard to achieve due to lack of integration among public transport modes. There is no proper and realistic transportation master plan for Dhaka city although it is necessary to integrate the transport modes in order to provide a balanced, multimodal system. (Shrivastava and O'Mahony, 2009) Little is done to create a platform of providing a continuous transport service to the travelling public. Rather than entering into destructive competition, it would be to the benefit of both the transport industry and the user if services are complemented where possible. Thus arises the need of modal integration. (Maluluke and Baloyi, 2000)

Modal integration or integrated transportation system can be defined as the integration of some or all of the different public transport modes (mainly trains, buses and taxis) into the public transport system, in such a way that these modes support and complement each other and that they operate as a coordinated public transport system, while providing an effective efficient and affordable service to the user. To implement integrated transportation system, the following aspects should be achieved in a project or in an area, preferably as many as possible:

- An integrated network,
- Integrated schedules,
- Proper transfer facilities,
- A common ticketing and fare system, including through-ticketing, and a combined information system, including call centers.

Transport plans must be so developed as to "give higher priority to public transport than private transport by ensuring the provision of adequate public transport services and applying travel demand management measures to discourage private transport" (Pillay and Zyl, 2000).

3.1 Requirements/ Objective of Effective Modal Integration

An effective modal integration system should meet the following requirements/ objectives (Pillay and Zyl, 2000):

- higher priority to public transport with sufficient facilities and services, utilization of scarce resources and expensive infrastructure
- main focus on the movement of people and not on the modes and integration of transport and land-use
- cooperation among and support of different government levels and various modes
- availability of funds through public-private-partnerships (PPPs) and clarity on the policy of government
- formalization and regulation of public transport, legislative framework on national and provincial level, right institutional structures
- Proper public transport planning and vision.

3.2 Benefits of Modal Integration

Betterment of Public Transport

Implementation of modal integration results in increased rail ridership and revenue, more marketable and attractive environment for riders, reduced route supervision requirements if several feeder routes terminate at transfer interchange. Rail transport is inflexible as it needs the support of other modes to ensure door to door service. The quality of rail transport service would be substantially enhanced by introducing modal integration if all the essential features are made available. (Maluluke and Baloyi, 2000)

Bus transport would also obtain improved fare income and reliance of passengers due to the synergy of effective modal linkages to satisfy the user. It is expected that there should be a significant modal shift from private to public transport and reduction of flow of private vehicles in the central business area (Maluluke and Baloyi, 2000)

Congestion Alleviation

Traffic congestion could be minimized by the introduction of modal integration as transport entities would strive to keep their travel time as short as possible. Thus reduced air and noise pollution, environmental degradation, improved traffic circulation, economic benefits due to less-congested corridors can be achieved (PADECO, 2000). A well-coordinated transport system, where different modes compliment each other, can be termed a prerequisite for lessening congestion.

Moreover, greater accessibility and mobility to business hubs, potential time-savings along same route, wider choice of transport services at transfer interchange, greater transfer convenience at interchange, potentially improved service on under-supplied routes would be possible.

3.3 Shortcomings of Modal Integration

There might be some negative impacts of modal integration which are briefly stated in the following section. Fewer through-routes increases transfer frequency and travel time which may cause public dissatisfaction. Also, initially, there will be some problems faced by the users for the cancelled routes.

The construction costs for infrastructure (e.g. interchange centers, overpass, underpass etc.) and other facilities (e.g. footpath, cycle-lanes etc.) are very high. In addition, increase in traffic flows around and crowding at interchanges slows down traffic circulation (e.g. Manila) and increase noise and air pollution. (PADECO, 2000)

Many issues like lack of trust, violence, uncertainty and fear prevail for the current running bus industry; they generally have an idea that they will only be allowed to do feeder services. On the other hand, some passengers (e.g. elderly, disabled people etc.) dislike rail, bus, in general, public transport.

3.4 Modal Integration World Wide

The public transport system of **Paris** is a good example of modal integration. The underground and regional suburban train system, the bus and smaller systems such as the two light rail lines, are all interlinked and integrated, with regard to networks, scheduling, information systems, through-ticketing and transfer facilities. **Munich** in Germany, is one of the cities which measured the savings and improvements brought about by comprehensive modal integration; and those were significant. (Pillay and Zyl, 2000) **Tokyo** showed that, following the completion of railway construction, a bus company (owned by the rail company) successfully rearranged their bus routes to provide feeder services for rail users.

In **Singapore**, nearly all new town residents live within a 5 minute walk of a bus stop. And buses take about one third of all access trips to MRT stations. TransitLink Pte Ltd was formed to integrate fares, timetables and passenger information which led to the world's first stored-value fare card that can be used interchangeably for bus and rail travel. Officials have also recognized that the MRT system needs to be expanded and are seeking to upgrade feeder connections and add tertiary systems such as "travelators" and grade-separated sidewalk networks. (PADECO, 2000)

London's overall public transport network is integrated by a well-established rail network complemented by an extensive bus network and a ferry network. At major stations, purpose built bus interchanges have been developed to be within walking distance of the railway and underground stations, often manned by bus station staff and furbished with real time information systems (e.g. Countdown – which shows the number of minutes until the next bus is due to arrive). **Hong Kong** public transport services include railways, trams, buses, minibuses, taxis and ferries. This result in very high public transit mode share (90%) and very low vehicle ownership rates. (Litman, 2012)

A reduction in travel by bus and paratransit modes operating along LRT corridors was observed in **metro manila**. Problems in modal interchange and within-mode transfer have long created serious bottlenecks. It disrupts pedestrians and road traffic through chaotic informal intermodal terminals. A similar tendency was found in **Singapore** but was successful in reorganizing bus use as feeder services. Subway fares in **Seoul** and Skytrain fares in **Bangkok** are higher than bus fares and the government has not implemented a plan to integrate and coordinate both modes. The large number of buses combined with relatively little road and loading space creates congestion. Crowded buses can often be observed while overhead trains are virtually empty. Traffic management schemes to ensure drop-off, pick-up and turn-around facilities for buses, taxis and other feeder modes were not planned with sufficient time. The framework in Bangkok of BMTA acting as both regulator and operator causes conflicting interests and confusion in whether it should compete with BTS or provide a feeder supportive network. (PADECO, 2000)

4. PRESENT TRANSPORT SYSTEM SCENARIO

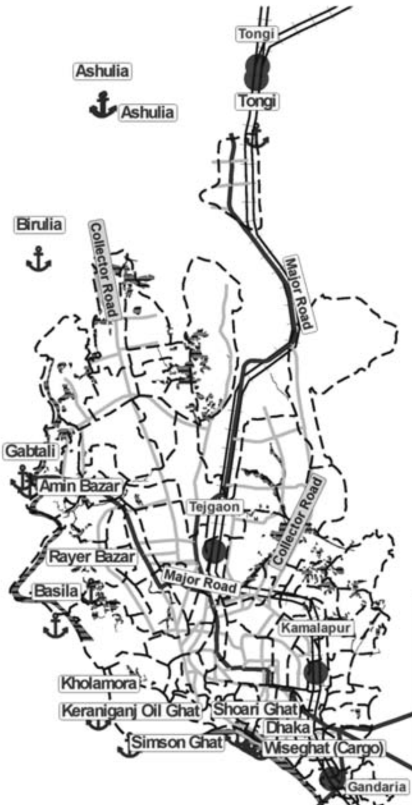
Despite being one of the fastest growing and most densely populated cities in the world, Dhaka has a rudimentary transportation system with some unique characteristics (e.g. absence of properly planned and organized mass transit system, excessive number of NMTs, dearth of road space which is shared by heterogeneous traffic mix etc.). Its current transport situation of different modes has been described briefly in the following sections.

4.1 Railways

Dhaka's railway network serves an estimated 28,000 passengers/day by operating 62 passenger trains (both intercity express and local) with the main railway station at Kamalapur. The train line runs from north to south, along the axis of growth of the city, and divides it into east and west part. Although it connects the city centre with Dhaka's suburban and satellite towns like Banani, Uttara, Narayanganj, Narsingdi and Joydebpur, the network is not used as commuter train line mainly because of numerous at-grade level crossings. Frequent train movement on this line will bring to a standstill the traffic in the city several times in a day. (Bhuiyan, 2007)

Dhaka Integrated Transport Study (DITS) stated about this in 1998: *"The main inter-city line entering from the north carries minimal commuter traffic. The* *branch line to Narayanganj, wholly within the study area, is entirely devoted to local traffic but is grossly under-utilized.*" There have been no significant changes of the situation in the following years.

Between Tongi in the north and Narayanganj in the south, there are ten existing stations: 1.Tongi Junction, 2.Airport, 3.Dhaka Cantonment, 4.Banani, 5.Tejgaon, 6.Kamalapur, 7.Gandaria, 8.Fatullah, 9.Chashara and 10.Narayanganj. All stations within Dhaka are quite well served by different transport modes. Adjacent to the Kamalapur Railway Station, is an Inland Container Depot (ICD) which handles about 70,000 containers/year. Two container trains operate daily between Chittagong and the ICD. On the other hand, total of 18 passenger trains/day (9 inbound and 9 outbound) halt at the Tejgaon Railway Station serving about 40,000 passengers/month. It is also the destination for all freight railway shipments except the trains that carry containers to the ICD at Kamalapur. From Tejgaon Railway Station some of the cargo is off-loaded onto trucks for distribution to various destinations while other portions are transported onward to other railway stations (e.g. Narayanganj) by a local shuttle train (Louis Berger Group and BCL, 2005). It is also used as a marshalling yard and workshop for all freight wagons. Located illegally on railway land, neighboring the station, is the Tejgaon Truck Terminal. Large number of trucks are parked, stored, being repaired there. Congestion on the surrounding roads is particularly severe due to limited space and other truck-stand related activities.



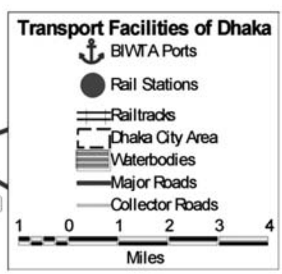


Figure 1: Transport facilities of Dhaka

The part of rail track between Tongi and Kamalapur Railway Station is about 23 km in length. Along this section, there are two sets of tracks (both Meter and Broad Gauge), and the condition is classified as "good" by Bangladesh Railway. There are 16 at-grade crossings of important roads which cause substantial delay and congestion. The segment between Kamalapur Station and Narayangani Railway Station is around 14 km, with only one set of tracks (Metre Gauge) and the condition of it is termed as “fair”. There are also several at-grade crossings in this portion, on some major roads which are the key entry points to Dhaka in eastern and southern side. At present there are 20 passenger trains/day operating between Kamalapur and Narayanganj Railway Stations (Louis Berger Group and BCL, 2005).

4.2 Waterways

One blessing Dhaka has is its encircling waterways. Buriganga, Turag, Balu, and Sitalakhya River flow around its perimeter. Once, there were also a number of canals and inland lakes throughout Dhaka. Regrettably, many of these canals and lakes have been filled up or blocked.

At present, huge amount of water transport-related activity occurs along the bank of the Buriganga River that borders on the southern edge of the old city area (mainly Sadarghat and Swarighat area). There are 3 kinds of movements which can be summarized as: (i) high volume of small boats (human powered) that move people and goods across the river, (ii) many large passenger launches that transport people to distant locations usually overnight and mostly to the southern parts of Bangladesh, (iii) various river vessels that transport goods and materials within the Dhaka city and its adjoining areas.

Sadarghat on the bank of Buriganga River is the main river port in Dhaka. The main terminal, which has berthing capacity for 40 vessels, handles daily an average of 100 arrivals and 100 departures (Louis Berger Group and BCL, 2005). These terminals are located in the overcrowded areas of the old city where not only roads are narrow but also occupied by traders and parked vehicles. As a consequence, chronic congestion, nonexistence of bus services, dependence on slow moving vehicles (NMTs) etc. are somewhat common in those areas. There is also a moderated level of activity northward along the Turag River on the west side of Dhaka as well as the Balu River on the east side of Dhaka.

Bangladesh Inland Waterways Transport Authority (BIWTA) was proceeding with the development of a Circular Waterways System around Dhaka. Data from their study shows that the most important landing station with respect to passengers is Swarighat, accounting for approximately 38% of all passengers, while the four designated major landing stations (Swarighat, Amin Bazar, Gabtali, and Ashulia), together account for almost 95% of all of the freight traffic (Louis Berger Group and BCL, 2005).

4.3 Roadways

4.3.1 Motorized Transport

4.3.1.1 Private Transport

The number of registered motorized vehicle increased very rapidly in Dhaka, from 3,03,215 in 2003 to 7,08,197 in June, 2012 (more than 40% of all registered vehicles in Bangladesh). It can be observed from BRTA statistics that number of cars and motorcycles have roughly more than doubled within this period. Motorcycles, cars and jeep-station wagons consist about 42%, 26% and 10% of total motorized vehicle in the city (BRTA, 2012).

According to Strategic Transport Plan (STP) for Dhaka (2005), auto-ownership is only 13 per 1000 population; and automobiles represent 17% of all trips excluding walk mode, 29% of trips by motorized vehicles, and 45% of trips by 4-wheeled motorized vehicles. Major portions (86%) of total motorized (non-transit) trips are made by medium and high income groups (52% of Dhaka's population) (DTCA, 2010).

All vehicles are imported; Bangladesh does not have any automobile manufacture or assembly plants. In 2001, almost 80% of imported automobiles were reconditioned or secondhand. However, as a result of a change in government policy, the proportion of new vehicles has increased since 2002. Currently, the proportion of used vehicles imported is about 60% (Louis Berger Group and BCL, 2005).

4.3.1.2 Public Transport

Bus and minibus services can be dubbed as a form of mass transit option to some extent for Dhaka because of its efficiency even in awfully unfavorable condition. Despite the fact that it comprises a small proportion (9.7%) of the mix that combines all vehicles and pedestrians, bus passengers account for 77% of all people (DevCon, 2009). Although the number of buses and minibuses has increased from 10,074 in 2003 to 19,643 in June, 2012, their overall percentage among total vehicles decreased from 3.3 to 2.8 (BRTA, 2012). It can be observed that only 10.4% roads are satisfactory for bus operation. Even by considering connector roads are suitable for bus flow, there is around 30% road available for bus services, which is only about 400 km (Bhuiyan, 2007; DevCon, 2009). Moreover, this road space is also shared by NMTs and as a result of absence of any bus priority measures, buses often come second when they compete for road space with other modes.

The bus fleet of Dhaka is not very old (Bhuiyan, 2007), but poor maintenance, inadequate technology, unavailability of required facilities and overall carelessness are main causes for their deplorable condition. Majority of buses manufactured in 2002 because government banned buses older than 20 years on that year. Thus, there was a rush to import or buy new bus-minibuses. Also, the introduction of CNG and support from government for conversion made an positive impact in 2003.

Nearly 70% of the bus routes' length is within 11 to 30 km (DTCA, 2010), which is about the extent, Dhaka city can be termed by length in north-south direction. It seems these routes crisscrossed the city and serving the users quite well. But in reality, there are unnecessary and unwanted overlapping of the routes, with sole intention of profit maximization and operational advantages. Most of the bus companies in Dhaka are small to medium size (roughly 70% of them have 11 to 30 buses) (DTCA, 2010). However, all buses of a company may not be owned by a single person, rather, generally, a good number of individuals own one or more buses, make a group, form and run a bus company. So, even these companies' buses ply on the roads like individually owned buses.

4.3.2 Non-Motorized Transport

4.3.2.1 Rickshaws

Rickshaws are the most significant mode of transport in Dhaka. They are the main public transport in about 900 km of local and narrow roads, with less than 8.75m width (69% of the DCC roads) where bus service is absent (Bhuiyan, 2007). In addition to rickshaws, there are two other types of non-motorized transport. The rickshaw-van is quite similar to a rickshaw, but with a flat carriage intended to carry goods and materials instead of passengers. The other form of is the "Thela" which is basically a push cart also used for same purpose, usually with one person pulling it and one or more persons pushing it. The number of rickshaw-vans and thelas is very small with respect to number of rickshaws.

Rickshaws account for 34% of all person trips in Dhaka increasing from 19% in 1998 (Louis Berger Group and BCL, 2005). The average length of rickshaw trips is 2.34 km and 61% of all rickshaw trips are made by people in the middle income levels (Tk12, 500 – 55,000 per month). It can be noted that almost 40% of the loaded rickshaws are being used by women and children, or people with goods and another 30% of users are students (Louis Berger Group and BCL, 2005).

There have been more than a few initiatives to limit the number of rickshaws in Dhaka with a view to eliminating rickshaws from the city some day. The DCC established regulations in 1985 that restricted the number of rickshaw licenses issued to 79,642 (DevCon, 2009). However, in reality, there is no effective mechanism for enforcement of the license requirement, thus the number of rickshaws plying the streets is many times the limit established by DCC. This results in the fact that some 80% of the fleet is operating illegally (Louis Berger Group and BCL, 2005). There is no information available about the actual number of rickshaws currently on street. STP (2005), AQMP study (2007) and CASE study (2009) estimated that there are more than 500,000, 250,000 and 500,000 rickshaws respectively.

In 2002, the DCC initiated the implementation of an *"NMT-Free Arterial Network – Phased Implementation Plan"* which targets phased withdrawal of NMTs from 11 major roads, over a period of two years (2004-2005). Due to various concerns and political sensitivity, the implementation has been curtailed (Louis Berger Group and BCL, 2005) and at present only 33 km of roads are rickshaw free (Bhuiyan, 2007).

4.3.2.2 Pedestrians

By far, walking is the most widely used mode of transport in Dhaka. Actually, walking is a matter of economic necessity for many people, particularly for urban poor. In spite of overall prevalence of walking, developing pedestrian facilities have always been ignored and most of the time, only added as an afterthought to road improvements. There are only about 400km of footpath within the DCC area, but they are beleaguered with frequent obstructions (e.g. vendors and hawker, temporary shops, shanties, stored or abandoned building materials and debris, parked cars, dustbins etc.) which block and reduce their general utility. As a result of nearly 40% of the footpaths is being occupied illegally, pedestrians are forced to walk in the street (Louis Berger Group and BCL, 2005). This phenomenon not only increases the risk of traffic-related pedestrian injuries and but also reduces the capacity of the road, thereby increasing congestion. It should be noted that pedestrians are involved in half of all road collisions in the city and two-thirds of all traffic related fatalities are pedestrians (Louis Berger Group and BCL, 2005).

4.3.2.3 Bicycles

Bicycles are a major component of the transportation system in many cities around the world including some developing countries such India and China. However, bicycles are not being used as a significant mode of transport in Dhaka. Bicycles comprised only around 2% of all vehicles and about 2% of the households own a bicycle. Some factors behind the low usage of bicycles can be identified as: (i) Cost: high price of bicycles, considering the relatively low income levels of the sector of the population who are most likely to use them (ii) Safety: absence of designated bicycle lanes or any other facilities in roads which are typically narrow, crowded and dangerous. In addition, the poor condition of the surface of many roads represents a serious hazard for bicycles. (iii) Culture & Security: it is neither suitable nor appropriate for women to use bicycles according to the cultural norms. Also, there are no suitable means to park and leave a bicycle unattended (Louis Berger Group and BCL, 2005).

Until significant changes occur regarding these factors, the role of the bicycle as a mode of transport will remain limited to few small groups who currently use them (i.e. students, clerical grade office workers, mechanics, shopkeepers, etc.) (Louis Berger Group and BCL, 2005).

5. STRATEGIES FOR ACHIEVING MODAL INTEGRATION IN DHAKA

5.1 Bus Rapid Transit

To make drastic improvement of the current pitiable transport scenario, the government has introduced The Strategic Transport Plan (STP), for Metro Dhaka, according to expert opinions and proper planning with help from development partners. It has recommended a package of about 50 projects for the development of transport infrastructure over 20 year period. Of most significant of the programs were three Bus Rapid Transit (BRT) routes within the development of six major corridors as mass transit routes as a means for achieving sustainable urban transport in the city. Three radial corridors as follows are thought to be potentially suitable for Bus Rapid Transit (BRT) introduction.

Corridor A: Starting in Uttara in the north and following Dhaka Mymensing Road, Pragati Road, DIT Road Toyenbee Circular Road to Saidabad Bus Terminal.

Corridor B: Starting at Gabtalli and following Mirpur Road, Zahir Raihan Sharani Road to Saidabad Bus Terminal

Corridor C: Starting at International Airport following Airport Road, Shaheed Tazuddin Road and ending in Ramna area

These three BRT corridors are now enthusiastically been considered by the government with support from the World Bank and Asian Development Bank. Most of the BRT Corridor C (BRT line-3) will go at grade. However, some parts of the alignment will be elevated in order to segregate it from the mixed traffic lanes, avoid pedestrian crossings and reduce number of road intersections. Anyhow, BRT will always go segregated from mixed traffic lanes *(ALG, 2012).*

5.2 Mass Rapid Transit

Metro Line 4: It is planned to serve the central corridor connecting the north, Uttara and the International Airport with Saidabad Bus Terminal. Beginning at Uttara, will come to the International Airport and could run at-grade possibly as far as the Cantonment Area at the north of New Airport Road. After the Cantonment Station, will go underground serving Mohakhali, Tejgaon, Mogh Bazar, Khilgaon and Kamalapur Station; terminating at Saidabad Bus Station.

<u>*Metro Line 5:*</u> Planned as a continuous loop, it will connect the high density residential areas of Gulshan, Dhanmondi and Mirpur and the developing areas to the west of the Cantonment Area. Furthermore, it is planned to provide two good east-west connections across the city spaced some 4 km apart.

<u>*Metro Line 6:*</u> This line is planned to provide a connection between the developing areas to the west of the Cantonment Area and the central area and Saidabad Bus Terminus. The alignment is based on Begum Rokeya Sarani, Sonargaon Road and Zahir Raihan Sharani.

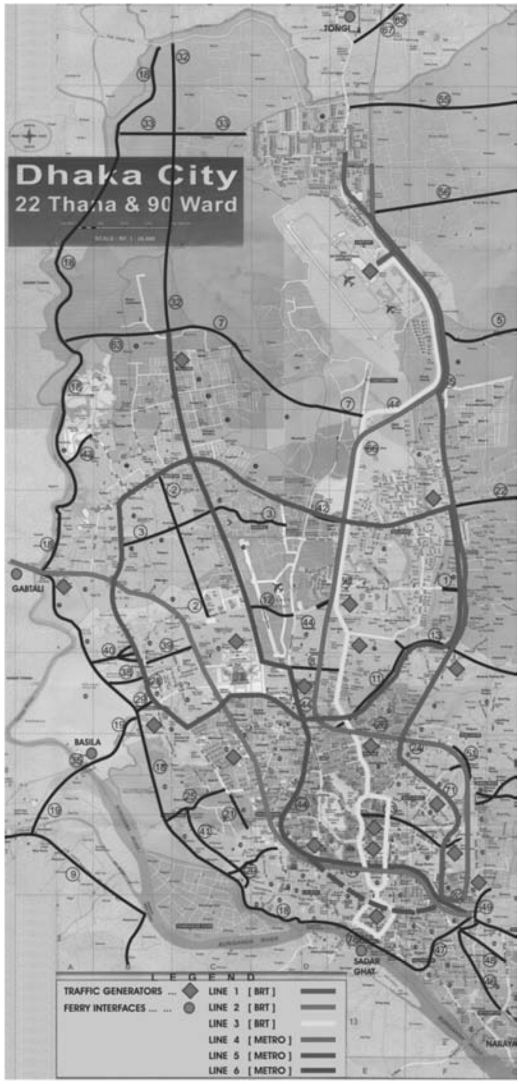


Figure 2: Proposed new roads, BRT & MRT lines

5.3 Railway Projects (Proposed and Ongoing)

Some railway related project proposals that have been made over recent years and continue to exist with some reservations include:

(a) Adding two more sets of tracks north of Kamalapur Railway Station (to Tongi) and one more set of tracks to the south (to Narayanganj);
(b) Building an Underground Railway Line or a Railway Mass Transit System in Dhaka;
(c) Constructing a Circular Railway Line around Dhaka, preferably using the city's flood protection embankment where available; and
(d) An Elevated Mass Transit System for Dhaka.

On the other hand, STP (2005) suggested about:

a. Relocation of the existing Inland Container Depot (ICD).
b. Relocation of the railway to an alignment east of Pragati Sharani and use of the existing alignment for other transport related purposes.
c. Terminating the rail line, and all rail services, at an appropriate northern point, establishing suitable station facilities (passenger and freight) and relying upon intra-urban modes to distribute and collect passengers and goods throughout the Dhaka urban area.
d. Elevating the railway along the existing alignment and substantially upgrading the services, possibly including urban commuter rail service (Gazipur – Dhaka – Narayanganj).
e. Reuse of the existing railway alignment for some type of mass rapid transit system, if the railway alignment is relocated and/or service is terminated at a suburban entry point.

Already, construction of a new ICD has been completed at Pangaon and converting meter and broad gauge lines to dual gauge rail tracks to and from Kamalapur is also finished.

5.4 Circular Waterway System

BIWTA study specified that (i) a substantial level of existing (2001) passenger and freight volume already using the western section of the Circular Waterway between Ashulia and Sadarghat, and (ii) a substantial increase projected for the future target years (2010 & 2020) (Louis Berger Group and BCL, 2005). BIWTA progressed with the implementation of the recommendations for the western section (Ashulia to Sadarghat) of the Circular Waterways System, including dredging and construction of landing stations. BIWTA initiated feasibility study for the eastern section of the Circular Waterways System (Ashulia to Demra), including waterway linkages to some of the existing canals. Then this section was expanded from a BIWTA-only project to involve Local Government Engineering Department and DCC, both with the responsibility for the constructing 15 new roads connecting to the landing stations.

5.5 Some Other Initiatives and Suggestions

Commuter Rail Service

Commuter rail service and shuttle trains will be introduced by Bangladesh Railway from Kamalapur to Narayanganj and also being considered for Tongi-Kamalapur route.

Future of Rickshaws

Rickshaws should be phased out from the major arterials and to be used as a feeder service for mass transit options.

Restructuring Current Bus Network

Changing the present bus network and routing; emphasizing on travel demand and based on present O-D matrix rather than with a view to boosting the revenue and operational simplicity.

6. CONCLUSION

Rapid urbanization, growth of vehicular population, unwarranted inflow of people in urban areas resulting in increase of urban poor are worsening the transport problem in Dhaka, like any other developing city in the world. But, it is a fact of life in Bangladesh that there are never, hardly ever, sufficient resources. So, to carry on progress in socio-economic field and prevent environmental pollution, a sustainable urban transportation system is required. The prerequisite for that is modal integration, which in case of Dhaka, according to STP, should be developed based on BRT and then MRT, with an eye to the urban poor.

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An Experimental Research on the Factors of Transit Stop Consolidation

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ABSTRACT

Bus stops consolidation can be an effective way to enhance the operation and hence the ridership of bus services. A multi-level mixed factorial experimental method is developed to analyse the factors of probable impact on stop consolidation. The experiments are executed on a mathematical model that consolidates transit stops according to the potential users travel time savings and accessibility. Six independent factors and three response variables were selected to run the experiments. The significance of the individual factors as well as their interaction levels were estimated. The findings indicated that the *distance between the stops* and the *maximum walkable distance* are the most influential factors. The *passengers' activity* and the *percentage of decreased passengers* were also found to be influential. The *average cruising speed* and the *frequency of service* has very little influence on the response variables. The study demonstrates the extent of influence of factors on consolidation decisions.

INTRODUCTION

In transit planning, stop consolidation refers to a process of removing, merging or re-locating stops. Stop consolidation has the most direct effect on travel time. This is due to the fact that each stop is characterized by certain delay elements such as deceleration and acceleration time, dwell time, time taken in the open and close doors and re-entering traffic delay.

Many models are developed by researchers to study and implement stop consolidation. Vuchic and Newell (1968) are the pioneer researchers who presented an analytical method to determine stop spacing. Furth and Rahbee (2000) used a discrete model combining Geographic Information System (GIS) and dynamic programming. Saka (2001) presented a mathematical model which is derived from the fundamental relationships among velocity, uniform acceleration or deceleration, and displacement. Chien and Qin (2004) proposed a mathematical model to determine optimum number of stops and location by minimizing total cost. Ibeas et al. (2010) proposed an optimal bus stop location and spacing model to minimize the social cost of all the transport system. Li and Bertini (2008) estimated the average stop spacing by their model using the Bus Dispatch System (BDS). Oliviera et al. (2008) designed a model comprising non-linear programming and heuristics to optimize bus stop spacing by minimizing users' average travel time. Alonsoa et al. (2011) proposed a bi-level optimization model, which includes a modal split function in a lower level and a social cost minimization function on the upper level.

Distance between stops is considered as the most important factor of consolidation. Many transport agencies have their own standards of distance between stops, which usually vary, depending on transit modes, population density etc. (El-Geneidy et al., 2006; Saka, 2001; Furth and Rahbee, 2000). Accessibility, another important factor of consolidation, often assessed by users' willingness to walk (Biba et al., 2010; Murray and Wu, 2003; Zhao et al., 2003; O'Sullivan and Morall, 1996) or tolerance of walking, which varies with the physical environment of the walking path (El-Geneidy et al., 2010; Wibowo and Olszewski, 2005; Zhao et al., 2003), different transit systems and places (El-Geneidy et al., 2010; O'Sullivan and Morrall, 1996). In the literature, transit demand after consolidation is mostly assumed to be unchanged or very small. Alonsoa et al. (2011) admit that demand may change and addressed this issue by considering modal split after stop consolidation.

This study identified six major factors that can influence consolidation decisions. These include the distance between stops, accessibility, passengers' activity, probable loss of passengers (change in transit demand), frequency of service and average cruising speed. A mathematical model is formulated by comprising all of these factors. The model computes the direct effect of consolidation (travel time savings) on each stop and uses this in a combinatorial procedure to determine the group of stops for consolidation that maximizes travel time savings. The impacts of the factors are assessed by an experimental design methodology and evaluated by statistical analysis. The major findings of the analysis are discussed. A case study of two routes in the city of Al Ain, UAE is also presented.

MODEL FORMULATION

The model makes a decision on consolidating a stop, *n*, based on the estimates of the direct impacts of the consolidation on users' travel time savings that could be materialized from consolidation. If the travel time savings are positive, a decision is made to consolidate the stop. Let $\boldsymbol{N}$ be the set of all stops along a transit route, the objective function is maximize the sum of the users' travel time savings that could be materialized by consolidating any of the $|\boldsymbol{N}|$ stops along the route. The objective function is stated as follows:

Objective Function: $Max \sum \Delta T_n \ , \forall n \in N, \forall \Delta T_n > 0$

The details of the model formulation are described in Hassan and Hawas (2013). In this article, only the basic equations (eqn. 1-3) are discussed. The users' travel time savings of stop n, denoted by ΔT_n, is estimated as the difference of the through users travel time savings, ΔT_n^T, and the affected users travel time changes, ΔT_n^A (eqn. 1).

$$\Delta T_n = \Delta T_n^T - \Delta T_n^A \quad (1)$$

$$\Delta T_n^T = (t_n^{\ddot{a}} \times N_n^T) + (t_n^d \times N_n^T) + (N_{n+1}^a \times N_{n\rightarrow n+1}^b \times \tau^b) \quad (2)$$

$$\Delta T_n^A = \Delta T_{n,wk}^A + \Delta T_{n,wt}^A + \Delta T_{n,r}^A \quad (3)$$

In eqn. 2, $t_n^{\ddot{a}}$ is the acceleration/deceleration time at stop *n*, N_n^T is the number of through passengers in bus passing through stop *n*, and $t_n^d$is the door opening/closing time. The term $(N_{n+1}^a \times N_{n\rightarrow n+1}^b \times \tau^b)$ in Eqn. (2) is the travel time that the alighting passengers at stop *n+1*, N_{n+1}^a, save because they leave the bus before the boarding of passengers, who shifted from stop *n* to *n+1*,$N_{n\rightarrow n+1}^b$, andτ^bdenotes boarding time per passenger in seconds. In eqn. 3, $\Delta T_{n,wk}^A$ is the change in walking time for affected passengers at stop *n*, $\Delta T_{n,wt}^A$ is the change in waiting time for affected passengers at stop *n*, and $\Delta T_{n,r}^A$ is the change in riding time for affected passengers at stop *n*.

The travel time savings of eligible stops are calculated with the assumption that the users will be divided among the adjacent (preceding and subsequent) stops after consolidation. In analyzing a particular stop, the adjacent stops are temporarily flagged as not eligible for consolidation, though they may yield positive travel time savings. Then, through the adopted iterative approach, we consider the possibility that consolidating a series of stops (consecutive stops) may provide positive travel time savings. As such, all possible combinations of consecutive stops (to be consolidated) are analyzed. The best combination according to the travel time savings is chosen for consolidation.

The model is iterative in nature. Following a particular consolidation decision, the model creates a new stop and link profile of the route, and then it re-iterates to check for further consolidations. The model is designed to maximize the number of stop consolidation decisions given that they yield to travel time savings.

EXPERIMENTS ON THE MODEL

The model is used to test the effects of the different input factors in various hypothetical scenarios. A multi-level (mixed) factorial experimental method (Montgomery, 2009) is used for this purpose, where all the probable combinations/scenarios are tested and analyzed. The objective of the experiments is to determine the most influential factors of stop consolidation.

Selection of Factors and Levels: The model has 16 different inputs; six of these were chosen for testing. These probable influential inputs are designated as “factors”. The factors and their levels are summarized in Table 1.

Table 1.Tested Factors and Levels.

Factors (unit)	**No. of Levels**	**Level 1**	**Level 2**	**Level 3**	**Level 4**
Distance between stops[1] (meters)	4	100-300	300-500	500-700	700-1200
Passengers' activity[2] (passengers/hour)	4	0-50	50-100	100-150	150-200
Average cruising speed[3] (km/hr)	3	15-30	30-45	45-60	
Maximum walking distance[4] (meters)	3	600	800	1000	
Frequency of service[5] (trips/hour)	3	2	4	6	
Percentage of decreased passengers[6] (%)	3	0	25	50	

[1]*Distancebetween the analysed stop and its preceding stop;* [2]*total number of boarding and alighting passengers at analysed stop;* [3]*average cruising speed on the preceding link section of the analysed stop;* [4]*maximum walkable distance of the transit service users;* [5]*frequency of the transit service;* [6]*probable decrease in passenger activity due to consolidation.*

Selection of Response Variables: Three response variables (outcome measures) are selected from the output of the model. These are: *the percentage of consolidated stops*, *percentage of travel time savings* and *percentage of operating time savings*.

Design of the Experiments: The experiments are designed as a multi-level (mixed) factorial experiment. To design a full factorial design with such mixed levels, a total of 1296 ($4 \times 4 \times 3 \times 3 \times 3 \times 3$) combinations of experiments are needed. As there is a correlation between distance between stops and average cruising speed, out of 12 combinations of these two factors, 2 combinations cannot be chosen (are not be feasible). These two combinations are the ones of relatively medium and high cruising speed levels (of 30-45 and 45-60 km/hr) with relatively low stop spacing (100-300 m) categories. The elimination of these infeasible combinations out of the 1296 possible scenarios reduces the total valid combinations to 1080. Ten runs are performed for each combination, with a total of 10,800 experiments.

The model is slightly adjusted to analyze only one route profile; updates and iterations were deactivated. Additional codes are written to consider all the experiments one by one; simulate 10 different scenarios (10 runs) and store the outputs for each run. Each experiment is run on a hypothetical route of 20 stops. Each experiment considers consolidating stops along the route excluding the origin and destination stops. Also, as iterations are deactivated, consecutive stops cannot be consolidated. That is, if stop n is consolidated, then stop $n + 1$ will be flagged for no consolidation. Out of the 20 stops along a route, a maximum of 9 stops can be consolidated (excluding the origin and destination stops as well as preventing the consolidation of consecutive stops). The percentage of consolidated stops is calculated from the maximum of 9 eligible stops.

ANALYSIS OF THE EXPERIMENTS

Importance of the Factors: The outputs of the experiments are analyzed in Minitab software. The effects of the factors are analyzed using analysis of variance (ANOVA). For the ANOVA tests, general linear models are developed for each response variables. The main effects of each factor and probable interaction effects (only second order interactions) are estimated (see Table 2). The regression equations of each response variables seem to be quite acceptable as the R-Sq values in each cases are more than 60%.The correlation between the factors and the response variables were also examined and presented in Table 3.

Table 2.ANOVA for the Outcome Measures.

Sources	**Outcome Measures(% of Sequential SS)**		
	Percentage of Consolidated Stops	*Percentage of Travel Time Savings*	*Percentage of Operating Time Savings*
Factors			
Distance Between Stops (F1)	28.69	12.96	29.66
Passengers' activity (F2)	13.44	21.98	3.86
Average Cruising Speed (F3)	0.27	1.14	1.14
Maximum Walking Distance (F4)	0.20	0.19	0.05
Frequency of Service (F5)	1.00	0.72	0.92
Percentage of Decreased Passengers (F6)	7.75	2.03	9.66
Interactions of Factors			
F1 F2*	5.09	8.65	2.41
F1 F3*	0.16	0.67	1.02
F1 F4*	0.42	0.55	0.15
F1 F5*	2.82	0.34	2.27
F1 F6*	11.36	3.06	19.18
*F2 * F3*	0.17	2.16	0.83
*F2 * F4*	0.68	0.75	0.18
*F2 * F5*	0.87	4.66	1.07
*F2 * F6*	0.37	0.47	0.44
*F3 * F4*	0.01	0.05	0.03
*F3 * F5*	0.01	0.14	0.01
*F3 * F6*	0.08	0.13	0.38
*F4 * F5*	0.01	0.02	0.01
*F4 * F6*	0.03	0.02	0.01
*F5 * F6*	0.25	0.03	0.71
Error	26.31	39.25	26.01
Total	100	100	100
R-Sq (%)	73.69	60.75	73.99
R-Sq(adj) (%)	73.46	60.41	73.77

Table 4 shows the importance of the factors according to the response variables. The assessment is done based on the percentage of Sum of Squares (SS) in ANOVA test (Table 2) and the strength of the correlation (Table 3). Importance of the factor is determined as very important (any of the effects is high/very high or strength of correlation is moderate/high), not important (all the effects are negligible and strength of correlation is weak/very weak) and important (all the other scenarios). From Table 3, we conclude that three factors are showing considerable effects on the response outputs/variables. These are distance between stops, passengers' activity and percentage of decreased passengers.

Table 3. Correlation Coefficients among the Factors and the Response Variables

Factors	Response Variables		
	Percentage of Consolidated Stops	*Percentage of Travel Time Savings*	*Percentage of Operating Time Savings*
Distance Between Stops	-0.494	-0.345	-0.486
Passengers' activity	-0.235	-0.339	-0.090
Average Cruising Speed	-0.093	-0.003	-0.046
Maximum Walking Distance	0.043	0.040	0.019
Frequency of Service	-0.090	0.082	-0.088
Percentage of Decreased Passengers	0.260	0.132	0.289

Table 4.Summary of the Factorial Experiment Results.

Response Variables	Factors	Effects observed from ANOVA*		Strength of Correlation **	Importance
		Main Effect	Interaction Effects		
Percentage of Consolidated Stops	*Distance Between Stops*	Very High	Moderate	Moderate	Very important
	Passengers' activity	Moderate	Minor	Weak	Important
	Average Cruising Speed	Negligible	Negligible	Very Weak	Not important
	Maximum Walking Distance	Negligible	Negligible	Very Weak	Not important
	Frequency of Service	Negligible	Negligible	Very Weak	Not important
	Percentage of Decreased Passengers	Minor	Moderate	Weak	Important
Percentage of Travel Time Savings	*Distance Between Stops*	Moderate	Minor	Moderate	Very important
	Passengers' activity	Very High	Minor	Moderate	Very Important
	Average Cruising Speed	Negligible	Negligible	Very Weak	Not important
	Maximum Walking Distance	Negligible	Negligible	Very Weak	Not important
	Frequency of Service	Negligible	Negligible	Very Weak	Not important
	Percentage of Decreased Passengers	Negligible	Negligible	Weak	Not Important
Percentage of Operating Time Savings	*Distance Between Stops*	High	High	Moderate	Very important
	Passengers' activity	Negligible	Negligible	Very Weak	Not important
	Average Cruising Speed	Negligible	Negligible	Very Weak	Not important
	Maximum Walking Distance	Negligible	Negligible	Very Weak	Not important
	Frequency of Service	Negligible	Negligible	Very Weak	Not important
	Percentage of Decreased Passengers	Moderate	High	Weak	Very important

* Very High (SS is more than 20%), High (SS is 15-20%), Moderate (SS is 10-15%), Minor (SS is 5-10%), Negligible (SS is less than 5%); derived from Table 3;
** Strong (r = –1.0 to –0.5 or 1.0 to 0.5), Moderate (r = –0.5 to –0.3 or 0.3 to 0.5), Weak (r = –0.3 to –0.1 or 0.1 to 0.3) and or Very Weak/none (r = –0.1 to 0.1)

Characteristics of the Important Factors: The main effects are plotted to observe the characteristics of the factors in different response variables (see an example in

Figure 1). The *percentage of consolidated stops* is more with lower *distance between stops* (Figure 1). This means that there is more chance or probability of stop consolidation at the lower levels of the *distance between stops* than at the higher levels. Savings in users travel time and operating time are also more if the *distance between stops* is low. The model consolidates stop(s) according to the travel time savings of the users at a particular stop. If the stop spacing is high, the extra walking time of the affected passengers is likely to exceed the travel time savings of the through passengers. Moreover, for high stop spacing, the accessibility (maximum walking distance) will likely decrease, and this may decrease the chances of consolidation. Therefore, for low levels of the *distance between stops*, the chances of consolidation decrease.

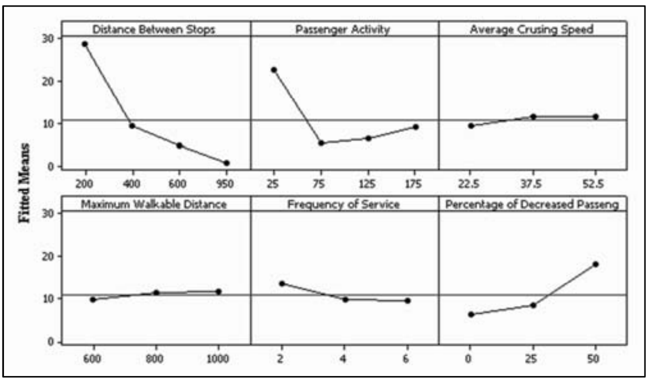


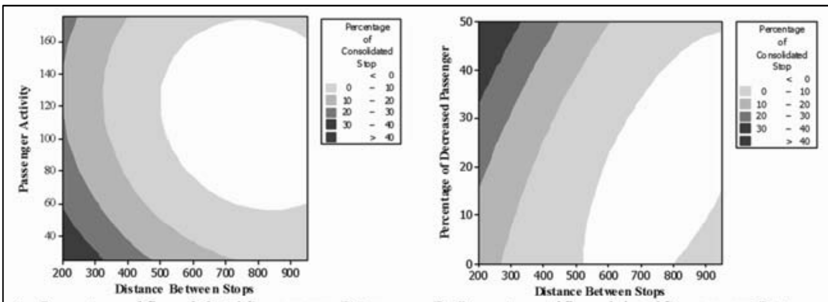
Figure 1. Main Effects Plot for *Percentage of Consolidated Stops*.

The main effect plots showed that the *percentage of consolidated stops* (Figure 1) and the *percentage of travel time savings* are more for the level of 0-50 passengers per hour. These two responses decrease sharply when the *passengers' activity* is increased to the level of 50-100 passengers per hour. When the *passengers' activity* is increased more (> 100 passengers per hour), the responses are slightly increased. *Passengers' activity* is a function of the boarding and alighting passengers. In the model, the travel time savings depends on the on-board passengers, which is a function of the numbers of boarding and alighting passengers, or passengers' activity. Theoretically, the more the on-board passengers at a stop, the more the chance of getting positive travel time savings. Although the *passengers' activity* at a particular stop can indicate the increase or decrease of the on-board passengers at that stop, it cannot itself indicate the size of the actual on-board passenger. Detailed examination is required to understand the relationship between the *passengers' activity* and the response variables.

The *percentage of consolidated stops* (Figure 1) and the *percentage of operating time savings* are more when the *percentage of decreased passengers* is higher. There is more chance or probability of stop consolidation with higher values of the *percentage of decreased passengers*. The *percentage of operating time savings* is also higher with higher values of the *percentage of decreased passengers*. If the passengers are decreased, the time loss due to walking and waiting will be decreased, compared to the case of no decrease in passengers. Therefore, the chance of travel time savings at the stop will be more, and this will eventually increase the chance of consolidation. Losing passengers will result in decreasing the operating time, as the boarding-alighting time for those passengers will be zero.

Maximum walking distance do not proved to be important in the experiments. Theoretically, the chance of consolidation should be higher at the high levels of the *maximum walking distance* than at the low levels. In the current experimental setting, there is very little chance (very few scenarios) to observe its effect. Therefore, a sensitivity test is performed in the "Case study" section to observe the effects of the *maximum walking distance* on the response variables.

Characteristics of the Interactions: The contour plots of important interactions (highlighted in Table 2) are also observed (see an example in Figure 2).The *percentage of operating time savings* and *the percentage of consolidated stops* are higher when the *percentage of decreased passengers* is higher and the *distance between stops* is lesser. The *percentage of travel time savings* and the *percentage of consolidated stops* are higher when the level of *passengers' activity* and the *distance between stops* are lesser, and vice versa. In a setting of moderate *passengers' activity* and low *distance between stops*, the *percentage of consolidated stops* is moderate. For a high level of *passengers' activity* and low *distance between stops*, the *percentage of stop consolidation* is high.



A. *Percentage of Consolidated Stops* versus *Distance between Stops* and *Passengers' Activity*

B. *Percentage of Consolidated Stops* versus *Distance between Stops* and *Percentage of Decreased Passengers*

Figure 2. Interaction Effects Plots for *Percentage of Consolidated Stops*.

CASE STUDY

A case study is conducted to assess the model validity in a real life situation. Two bus routes (running in Al Ain City in the United Arab Emirates) are selected. The data are collected and extracted from a study conducted by RTTSRC (Roadway, Transportation and Traffic Safety Research Center of United Arab Emirates University) (RTTSRC, 2009; Hassan et al. 2013). The model results show that a total of 30 stops (35.7%) can be consolidated along route 900. About 3.19% and 5.30% of the users travel time can be saved in the two directions which is equals to US$ 677,958yearly (users' travel cost is assumed to be US$ 8.5 per hour, according to Hess et al., 2004). The operating time saving is 3.54%and 5.62% in the two directions which is equals to US$ 186,950 yearly (operating cost per vehicle per hour is assumed to be US$ 60, according to Bertini and El-Geneidy, 2004). On route 930, a total of 36 stops (33.6% of the total eligible stops) can be consolidated. About 4.19% and 5.72% of the users travel time can be saved in the two directions (equals to US$ 836,781 yearly). The operating time saving is 3.81% and 6.22% in the two directions (equals to US$ 263,501 yearly).The study reveals that the percentage of consolidation is relatively high in the Town Centre (63% and 58% stops in this area are consolidated in route 900 and route 930, respectively). This may be attributed to the lower stop spacing in Town Centre area compared to the other areas. This finding is similar to the findings of Furth and Rahbee (2000), Saka (2001) and Murray (2001).

Sensitivity with Maximum Walking Distance: A test is performed to check the sensitivity of *maximum walking distance* (as discussed in the previous section). The results show that the *number of consolidated stops* is increased significantly with the increase of *maximum walking distance*. Savings in users' travel time and operating times are increased significantly as well. This concludes the significant impact of the *maximum walking distance* on the response variables.

CONCLUSIONS

This study pointed out the important determinants of consolidation by the experimental factorial design analysis. Among the six tested factors, the *distance between stops* appeared to be the most important factor. *Passengers' activity* has important effect on consolidation and users' travel time savings. The factor *percentage of decreased passengers* proves to be important for stop consolidation and operating time savings. The *maximum walking distance*, which is an indicator of accessibility, also shows significant effect on stop consolidation. Stop consolidation or savings in operating time do not depend much on the *frequency of service* or the *average cruising speed.*

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Comparison of Fuel-Cycle Emissions per Passenger Mile from Multiple Bus and Rail Technologies

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Abstract

This paper examines the fuel-cycle passenger-mile emissions from multiple bus and rail technologies using a travel-activity-based bottom-up approach. There is abundant literature on transit's emissions savings, but most prior studies rely on the top-down fuel consumption approach. While the top down approach paints a broad picture of transit emissions on a national or regional level, it cannot reflect changes in emissions as a function of operational characteristics such as passenger loading. It is also difficult to estimate passenger-mile emissions of new vehicle/fuel technologies for which fuel economy data are hard to obtain using the top-down approach. This paper develops a unified load-based methodology framework that compares fuel-cycle passenger-mile emissions across transit technologies including alternative fuels and advanced technologies. The methodology reflects the intricate trade-offs between the increased total emissions and decreased passenger-mile emissions as passenger load increases under specific local meteorological and route settings. Using the load-based methodology, the paper demonstrates the varying levels of emissions savings of transit fuels and technologies giving different passenger loadings scenarios. The methodology presented in this paper serves as the foundation of a transit emissions calculator currently under development. The calculator will prove instrumental for local transit agencies to compare fuel/technology alternatives in terms of emissions savings.

INTRODUCTION

There has been ongoing discussion on the role public transportation plays in combating climate change. As the Federal Transit Administration (FTA) summarized in a report, public transportation can provide greenhouse gas savings through two possible avenues: "providing a low emissions alternative to driving" and "facilitating compact land use" (Hodges, 2009). The scope of this paper is limited to the operating emissions of transit vehicles, including bus and rail, without taking into account the impact transit may have on land use patterns. To this date, the literature on the comparison of per-passenger-mile emissions from transit modes and emissions from driving is mostly based on reported or estimated fuel and energy consumption data, e.g. Chester (2008), Hodges (2009), Weigel (2010). These studies calculate emissions from energy inputs, such as electricity and fossil fuels, using the average emission factors for the specific energy input without considering vehicle operating conditions. This "top-down" approach is very useful in estimating national- and regional-level emission inventories, because transit agencies typically record and report fuel and energy consumption data.

Alternatively, emissions can be estimated using a “bottom-up” approach based on vehicle activity (EPA 2012b). Engine or electric motor load can be estimated based on instantaneous speed, acceleration, grade and vehicle weight for every second of vehicle operation. Emissions can then be estimated based on load. The strength of this approach is the precision and flexibility when it comes to route-level emissions analysis. It is useful for policy making and planning efforts because the load-based approach can reflect changes in emissions in response to changes in vehicle operations such as the introduction of an idle-reduction program and the implementation of transit signal priority projects. Moreover, the load-based approach allows for comparison of policies and plans across routes. For example, a hybrid-electric bus may be very effective in reducing greenhouse gas emissions for a particular type of route, but may not prove to be as effective for another type of route with different grade, speed limit and number of stops. The load-based approach is also capable of precisely and easily estimating changes in emissions at different passenger loading levels by including the changes in vehicle weight in the estimation of engine load.

This paper will demonstrate the use of load-based approach in estimating passenger-mile emissions for transit buses and rail. First, the load-based methodologies will be presented in detail. Then, the paper describes the data and scenario settings for the demonstration. Results from conventional diesel buses, compressed natural gas (CNG) buses, gasoline vans, diesel-electric commuter rail and all-electric heavy rail will be compared and discussed. The goal of this paper is two-fold: 1) to showcase the feasibility of estimating transit emissions, including both bus and rail modes, using the load-based approach, and 2) to add to the literature the comparison of bus and rail emissions, with an emphasis on passenger loading levels.

METHODOLOGY

Bus Technologies

This paper uses the load-based approach adopted in the U.S. EPA MOtor Vehicle Emission Simulator (MOVES) model. Second-by-second vehicle activity is categorized into operating mode bins based on vehicle specific power (VSP) for light-duty vehicles such as shuttle vans, or scaled tractive power (STP) for heavy-duty vehicles such as transit buses. The operating mode bin distribution is then applied to bin-specific emission rates to obtain total emissions. Currently, the MOVES model does not include a road grade component in the STP calculation for heavy-duty vehicles. It is also difficult to apply different passenger loadings in the modeling process. Therefore, the authors deconstructed the MOVES model by building an operating mode bin calculator and a MOVES-Matrix emission rate lookup table.

Operating Mode Bin Calculator

According to the MOVES User Guide (EPA 2012a), the formulae for VSP and STP calculations can be written into a unified equation as:

$$VSP(STP) = (A/M)\cdot v + (B/M)\cdot v^2 + (C/M)\cdot v^3 + (m/M)\cdot(a + g\cdot\sin\theta)\cdot v$$

where
A = the rolling resistance coefficient [kW·sec/m],
B = the rotational resistance coefficient [$kW \cdot sec^2/m^2$],
C = the aerodynamic drag coefficient [$kW \cdot sec^3/m^3$],
m = mass of individual test vehicle [metric tonnes],
M = fixed mass factor,
v = instantaneous vehicle velocity at time t [m/s],
a = instantaneous vehicle acceleration [m/s^2],
g = gravitational acceleration with the value 9.8 m/s^2
θ = the fractional road grade in percent grade angel.
The MOVES default values for terms A, B, C, m and M are summarized in Table 1

Table 1 Source Type Physics

Source Type Name	Rolling Term A	Rotating Term B	Drag Term C	Source Mass m	Fixed Mass Factor M
Light Commercial Truck (Shuttle Vans)	0.235008	0.00303859	0.000747753	2.05979	2.05979
Transit Bus	1.0944	0	0.00358702	16.556	17.1

To incorporate the effect of passenger load on VSP/STP, one needs to add the mass of passengers to the mass of the vehicle, such that

$$m = n \cdot w + m_d$$

where
n=number of passengers,
w=average passenger weight, default to 150 lbs,
m_d=default vehicle weight (source mass) as shown in Table 1.

MOVES-Matrix Emission Rate Lookup Table

Once the second-by-second VSP or STP is calculated, vehicle activities are categorized into 23 VSP/STP operating mode bins. Readers are referred to the MOVES User Guide for detailed definitions of the operating mode bins. A MOVES-Matrix emission rate lookup table was developed for light commercial trucks as well as transit buses using the processes described in Xu et al. (2013a). The resulting lookup table consists of emission rates for diesel, gasoline, and CNG shuttle vans and transit buses for each of the 23 operating mode bins under the local settings of Atlanta, GA in July.

The methodology also includes upstream fuel-cycle emissions, in addition to the direct emissions based on the MOVES emission rates. Total energy consumption is estimated using the VSP/STP approach outlined above. Then the GREET 2012 fuel-cycle emission rates, expressed in grams per mmBTU, are applied to obtain total upstream emissions.

Rail Technologies

Similar to the methodology for buses, the rail methodology starts with modeling the instantaneous tractive power requirements and estimate notch distributions, and then estimates an array of pollutant emission levels specific to operating conditions.

Rail Duty Cycle Processor

The tractive power output of diesel-electric trains and their engine related emissions can be estimated from their duty cycle, i.e., time spent in each throttle positions (notches). A locomotive's throttle positions can be simplified as an idle notch and eight traction notches where notch 8 represents maximum power output. Each notch has a specific power range and operates in a steady state with relatively constant fuel consumption and emission rates (Gould and Niemeier 2009). The Calculator provides two default categories of notch power ranges representative of locomotives manufactured by General Motors and General Electric Company. These categories are based on the findings of a study by Booz Allen Hamilton, Inc (1991). The ranges are defined by the percentage of rated engine power (or de-rated engine power when locomotive is used to supply hotel load) that a train is using at any instantaneous time. Users can also define their own unique power ranges. Table 2 shows the power ranges for each of the eight notches used in the notch-based emissions analysis.

Table 2 Definitions of Notches

Notch	GM Locomotives	GE Locomotives
Idle	$0 \leq IP < 5$	$0 \leq IP < 5$
1	$5 \leq IP < 11$	$5 \leq IP < 10$
2	$11 \leq IP < 25$	$10 \leq IP < 22$
3	$25 \leq IP < 35$	$22 \leq IP < 34$
4	$35 \leq IP < 47$	$34 \leq IP < 50$
5	$47 \leq IP < 67$	$50 \leq IP < 66$
6	$67 \leq IP < 90$	$66 \leq IP < 84$
7	$90 \leq IP < 98$	$84 \leq IP < 98$
8	$98 \leq IP$	$98 \leq IP$

Note: IP means instantaneous power as a percentage of rated or de-rated engine power
Source: adapted from Booz Allen Hamilton (1991)

To assign a specific notch to every second of rail operations, total tractive power requirements must be estimated. The Calculator estimates tractive power requirements by first determining the instantaneous notch position for each second of the trip. The estimation of total tractive power requirements consists of five components: 1) instantaneous unit moving resistance, 2) starting tractive effort, 3) acceleration and deceleration resistance, 4) hotel load, and 5) energy recovery from regenerative braking. The methods to estimate each component are described in detail below.

Instantaneous Unit Moving Resistance

For every second of the trip the instantaneous unit moving resistance is estimated from the Modified Davis Equation (Hay, 1982). The unit moving resistance is estimated separately for passenger rail cars and the locomotive unit due to their different weights. By this it is assumed that all the passenger cars in a train have the same weight. The formula setup is as below:

$$R = \left[\left(0.6 + \frac{20}{w_p} + 0.01V + \frac{KV^2}{w_p n_p}\right) + \left(0.6 + \frac{20}{w_l} + 0.01V + \frac{KV^2}{w_l n_p}\right)\right] * 0.85 + [20 * \theta S + 2 * \omega]$$

w_p = weight per passenger rail car axle (tons)
w_l = weight per locomotive unit (tons)
V = instantaneous speed (mph) of train
K = train drag coefficient
n_p = number of axles per passenger rail car
n_l = number of axles per locomotive unit
θ = slope or track gradient at the instantaneous location of the train. Only positive slopes are considered.
ω = instantaneous acceleration of the train. (cm/s^2)
R = unit resistance to moving train (lb/ton)

For every 1% increase in track gradient there is an additional resistance equal to 20 lbs/ton per percent grade (Gould and Niemeier, 2009). According to Hay (1982) the Modified Davis Equation is applicable to train speeds up to 60 mph. For higher speeds the equation tends to overestimate unit moving resistance and Totten's revisions (Hay 1982) would be required. However, the framework uses the modified Davis Equation because it will be applicable to most rail transit operations in existence within the US. Furthermore, Hay (1982) recommends that a factor of 0.85 (for conventional post-1950 cars) should be applied to the equation to avoid overestimation.

Starting Tractive Effort

The starting tractive effort or resistance is estimated whenever the train moves from an idle position. This happens at the start of the trip and stations where the train stops temporarily for passengers to alight or board. This framework uses the values recommended by the Chattahoochee Locomotive Company (railspur.com). The values are as given below.

- Grade Resistance: 20 lbs. per ton of train weight per percent of grade. Only positive grades contribute to this resistance.
- Bearing Resistance: 10 lbs. per ton at 50 F. Add 0.1 lbs. per degree F below 50 F. Subtract 0.1 lbs. per degree F above 50 F.
- Track Resistance: For 130 lbs. track use 0 lbs. per ton. For 115 lbs. rail use 1 lb. per ton. For 100 lbs. rail use 2 lbs. per ton.
- Weather Resistance: For wet rail use 2 lbs. per ton. For Ice/snow on the rails use 10 lbs. per ton.

- Track Condition: For good rail and crossties use 0 lbs. per ton. For poor rail and fair crossties use 2 lbs. per ton. For poor rail and poor crossties use 7 lbs. per ton).

The total estimated starting tractive effort is compared to the maximum rated starting tractive effort of the locomotive and the lesser is used in the analysis.

Acceleration and Deceleration Resistance

When a train is not travelling at a uniform speed such as during acceleration or deceleration, there are additional resistances to motion. For every cm/sq. sec of acceleration Profillidis (1995) showed that the additional resistance is about 2 lbs. per ton of train weight. To estimate this additional resistance the framework uses the second-by-second speeds to estimate either the instantaneous acceleration or deceleration of the train. This value is then multiplied with the recommended value. Theoretically, more force will be required to stop the train than to accelerate it. However, the deceleration forces have been approximated just as acceleration force.

Hotel Load Estimation

For diesel-electric locomotives hotel load requirements can be met by output from the prime mover (locomotive unit) or by a separate auxiliary power unit (APU). When the requirement is met by output from the prime mover, it is done at the expense of tractive power and the rated engine power is usually de-rated by the amount that is dedicated to supplying the hotel load. This is necessary to ensure constant AC power output. Therefore, if say a 3200 hp engine is de-rated to 2700 hp to accommodate hotel load supply from the engine, maximum power for traction would be achieved in a notch position lower than notch 8. Therefore, it is important for models to determine the maximum operating notch when hotel load is supplied from the locomotive because a higher notch will not provide any additional power in real life but it would erroneously introduce higher notch-specific emission rates into the analysis.

Maximum hotel load demand per passenger car has been set at 25 kW. The methodology considers three different operating levels for climate control in the passenger cars. “Normal” level is set at a third of the maximum demand. “High” level is set at two-thirds of the maximum demand. “Maximum” level is set at full capacity. Furthermore, hotel load demand for passenger cars is different and higher than hotel load demand for the locomotive unit. For locomotive hotel load estimation, the methodology uses 20 percent of the estimated hotel load per coach car under “Normal” operating level.

Energy Recovery from Regenerative Braking

The framework also includes analysis for estimating power recovery on trains with regenerative braking systems. The default value for the expected efficiency is 5 percent. According to the International Union of Railways, the potential recovery will be between 5 – 10 percent.

The total power for diesel-electric trains is calculated as the sum of the total tractive power and total hotel load. It is necessary to separate these two components because hotel load supply is not affected by throttle shifts in the engine.

However, for all-electric trains these two components are not separated because power supply for traction and hotel load comes from just once source with the same emission rates respectively. The modeling of tractive power for all-electric trains is similar to that of diesel-electric trains.

Development of Rail Emissions Rates

The emission analysis for diesel-electric trains is in four parts. The first part is a notch based analysis for tractive power generation. The other parts are based on fuel consumption. The second part yields related emissions for hotel load supply. The third part estimates equivalent emissions for SO_2 and CO_2. The fourth part produces the related N_2O and CH_4 emissions.

Notch Based Analysis

For the notch based analysis the spread sheet uses notch specific emission rates (g/bhp-hr) for CO, NOx, HC, PM_{10} and $PM_{2.5}$. $PM_{2.5}$ is estimated as 0.97 times PM_{10} (EPA, 2009) for each notch. To obtain the notch emissions in grams, the average power rating for each notch is used to multiply the emission rates to obtain g/hr. values. Then notch duty cycles are weighted by dividing by 3600 (number of seconds in an hour). The weighted duty cycles are then used to multiply the g/hr. values to obtain notch specific emissions in grams. The average traction related emission for the trip is then obtained by summing across the notches for each pollutant.

Fuel Consumption Based Analysis

To obtain the equivalent fuel combustion emissions for hotel load functions the total hotel load in horsepower – hour is first be converted to equivalent gallons of diesel. Then, the average of all notch specific emission rates (g/bhp-hr) is multiplied by a factor of 20.8 to convert it to g/gal emission rates (EPA, 2009). Next this average g/gal rate is then multiplied with the estimated number of diesel gallons to obtain emissions in grams.

SO_2 and CO_2 emissions estimates are based on equivalent fuel required for the entire trip. The total power (tractive and hotel load) required for the trip in horsepower-hour is converted into gallons of diesel as described above. The emission rates for SO_2 and CO_2 are calculated based on sulfur and carbon fuel content respectively.

Currently the EPA does not have locomotive emission rates for N_2O and CH_4 emissions. However, EPA advises that where emissions are needed for these pollutants one may assume the rates for diesel engines with similar technology. Based on the guidance EPA has provided in the Greenhouse Gas Inventory Protocol Core Module Guidance (EPA, 2008), the methodology has adopted emission rates for 0.0048 g/mi and 0.0051 g/mi for N_2O and CH_4 respectively. These rates are multiplied with total trip length in miles to estimate the emissions respectively.

This framework uses the available emission rates from power generation in user-specified US States. For all-electric trains, emissions are estimated by using emission rates related to power generation in US States. These rates are available in GREET 2012 (Argonne National Lab, 2012). The applicable rates are selected based on the State of the transit agency.

DATA AND SCENARIO DESCRIPTION

This section overviews the data settings that are employed in the example analysis. Readers are referred to Xu et al. (2013b) for a detailed description of the Calculator interface, including inputs and outputs, as well as an example application for bus technologies showing how to specify the settings and obtain results.

Data Sources

For the analysis of buses, the EPA Heavy-Duty Urban Dynamometer Driving Schedule (HD-UDDS) is used. The HD-UDDS cycle represents high-speed operation for buses and tractor trailers. The duration of this cycle is 1060 seconds, traversing a distance of 5.55 miles with an average speed of 18.86 miles per hour (mph). The HD-UDDS cycle was chosen because it was published by the EPA and is utilized at the National Vehicle and Fuel Emissions Laboratory. The HD-UDDS cycle data can be found on the EPA website[1].

For the analysis of rail, an empirical rail driving schedule is used. The research team collected time, speed, and location data using a handheld GPS unit on a train operated by the Metropolitan Atlanta Rapid Transit Authority (MARTA). The empirical data was collected from the Airport Station to the Garnett Station for 303 seconds, traversing approximately 3 miles. 1% grade is assumed. The authors are in the process of obtaining more rail operations data from transit agencies.

Scenario Definitions

Location and Meteorology Settings

All analysis in this paper assumes the summer conditions of Atlanta, GA, with an average temperature of 87.3 and relative humidity of 53.8%. The general terrain of Atlanta is rolling, so an average 1% road grade is assumed to be present on urban unrestricted roads on which transit buses typically operate. Electricity generation mix for the state of Georgia is used in fuel-cycle emissions analysis for electricity consumption.

Occupancy Assumptions

The occupancy assumptions are the basis of the comparisons described in the Results section. For 40-foot transit buses, three passenger loading levels are assumed: 5

[1] US EPA. Dynamometer Drive Schedules. http://www.epa.gov/nvfel/methods/huddscol.txt Retrieved on April 24, 2013.

passengers for off-peak buses, 9 passengers for average bus occupancy (FTA, 2009), and 40 passengers for peak buses. These assumptions are in agreement with comparable studies such as Chester (2008). For comparison purposes, shuttle vans are analyzed as an alternative to full-size buses for off-peak operations with 5 passengers per van.

All electric heavy rail trains are assumed to have 10 cars per train, with a seating capacity of 45 passengers per car. During peak hours, the cars are assumed to be 80% full, and during off-peak hours the assumed occupancy ratio is 10%. The paper uses an occupancy ratio of 37% for average conditions, based on MARTA data reported in the National Transit Database.

Diesel electric commuter rail trains are assumed to have 15 cars per train, with a seating capacity of 90 passengers per car. The peak-period occupancy ratio is 80% and the off-peak ratio is 10%, with an average of 37%, according to the National Transit Database.

RESULTS

Emission results are compiled for greenhouse gases, including atmospheric Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), and CO_2 equivalent, and criteria pollutants, including Carbon Monoxide (CO), Volatile Organic Compounds (VOC), Oxides of Nitrogen (NO_x), Particulate Matters ($PM_{2.5}$ and PM_{10}), and Sulfur Dioxide (SO_2). Table 3 summarizes the per passenger-mile emissions for transit buses, shuttle vans, all-electric heavy rail and diesel-electric commuter rail under peak-period, average, and off-peak conditions. For transit buses, ultra-low sulfur diesel (ULSD) and CNG fuel options are compared. Shuttle vans are assumed to run on gasoline.

The results show that the load-based approach produces comparable emission estimations as the top-down approach using fuel consumption data, such as results presented in Chester (2008) and Hodges (2009). Diesel transit buses produce 89 grams (approximately 0.19 pounds) of CO_2e per passenger mile with the peak-period occupancy. During off-peak periods when occupancy is as low as 5 passengers, diesel transit buses produce 661 grams, or 1.46 pounds, CO_2e per passenger mile. Under average conditions of 9 passengers per bus, the per-passenger-mile emission rate for diesel buses is 368 grams, or 0.81 pounds. The average per-passenger mile CO_2e emission rate is 187 grams for all-electric heavy rail, and 115 grams for diesel-electric commuter rail, assuming the Georgia electricity generation mix. The rail emission estimates only include fuel-cycle emissions, without considering emissions from the construction and maintenance of the tracks, yards, and stations.

Under the local and route settings, CNG buses offer emissions savings in CO2e and VOC. However, from a fuel-cycle perspective, CNG performs worse than ULSD for CO, NO_x, $PM_{2.5}$, PM_{10} and SO_2. Because some criteria pollutants have localized effect while others have a regional impact, the comparison between CNG and diesel should be conducted on a case-by-case basis, taking into account the source, location and effect of each pollutant.

Considering the high per-passenger-mile emissions for transit buses under off-peak passenger loading conditions, shuttle vans offer significant emissions savings. With 5 passengers onboard, gasoline shuttle vans produce 121 grams of CO2e per passenger mile, about 18% of what a diesel transit bus produces under the same condition. Using vans as a substitute for off-peak periods also saves emissions in all criteria pollutant species.

A meticulous reader will notice that the emission rates per passenger-mile do not have a linear relationship with the number of passengers. For example, the number of passengers during peak hours is 8 times as many as the number of passengers during off-peak hours. However, the per-passenger-mile CO_2e emission rate during off-peak hours is about 7.4 times as much as that of peak hours. The non-linear relationship is due to the increase in engine load as the number of passengers increases.

Table 3 Emissions per Passenger Mile in Grams

Mode	Bus						Van	AE Heavy Rail			DE Commuter Rail		
Passenger Loading	Peak		Average		Off-Peak		Off-Peak	Peak	Avg.	Off-Peak	Peak	Avg.	Off-Peak
Fuel Type	ULSD	CNG	ULSD	CNG	ULSD	CNG	Gas.	Elec.	Elec.	Elec.	ULSD	ULSD	ULSD
CO_2	86.8	62.7	360.0	259.0	647.0	464.0	118.0	89.8	186.0	668.0	47.1	112.0	351.0
CH_4	0.087	0.203	0.355	0.822	0.631	1.460	0.107	0.001	0.003	0.010	0.055	0.132	0.412
N_2O	0.000	0.002	0.001	0.009	0.002	0.016	0.002	0.001	0.003	0.011	0.000	0.000	0.001
CO_2e	88.8	67.6	368.0	279.0	661.0	500.0	121.0	90.3	187.0	671.0	48.3	115.0	360.0
CO	0.062	0.537	0.271	2.220	0.488	3.990	0.401	0.079	0.164	0.588	0.075	0.180	0.564
VOC	0.009	0.005	0.037	0.022	0.065	0.039	0.035	0.002	0.003	0.012	0.016	0.040	0.126
NO_x	0.148	0.170	0.634	0.699	1.140	1.250	0.098	0.067	0.138	0.495	0.455	1.120	3.550
$PM_{2.5}$	0.004	0.003	0.016	0.011	0.029	0.019	0.005	0.004	0.009	0.033	0.012	0.029	0.093
PM_{10}	0.007	0.008	0.027	0.031	0.047	0.055	0.008	0.008	0.017	0.061	0.014	0.034	0.107
SO_2	0.022	0.025	0.088	0.100	0.156	0.178	0.028	0.300	0.621	2.230	0.021	0.050	0.155

Passenger loading assumptions:

Buses and vans: Peak—40; average—9; off-peak—5.

AE heavy rail: Peak—80% full; average—37% full; off-peak—10% full. Number of cars per train: 10. Capacity per car: 45.

DE commuter rail: Peak—80% full; average—32% full; off-peak—10% full. Number of cars per train: 15. Capacity per car:

CONCLUSIONS AND DISCUSSIONS

This paper demonstrated using the load-based approach to estimate emissions per passenger mile for multiple bus and rail technologies. The results show that the load-based approach produce comparable emissions estimates as the top-down fuel consumption approach. The similarity of results between the two approaches offers evidence of validity for the load-based approach.

When compared across modes, the fuel-cycle emissions per passenger mile for rail are generally lower than the corresponding per-passenger-mile emission rates for transit buses. The caveat is that the emission estimates presented in this paper do not include emissions from the construction and maintenance of the vehicles and infrastructure. Within the non-fixed-guideway modes, shuttle vans could offer significant emissions savings during off-peak hours as compared to full-size transit buses.

The load-based approach offers great flexibility in policy analysis that is not included in this paper. The bus and van emissions are estimated based on a high-speed test cycle, and could be very different under different operating conditions such as a low-speed cycle featuring stop-and-go conditions. The load-based approach is capable of reflecting the changes in emissions under different route scenarios so that agencies can customize fleet purchases to different route types. In addition, the load-based approach offers a means to predict emissions savings from policy changes such as an anti-idle program for buses and a change in station dwell time for trains. The methodology outlined in this paper is the basis of the Greenhouse Gas Emissions Management Calculator currently under development. The spreadsheet-based, interactive calculator aims to provide agencies with a powerful yet easy-to-use tool for planning efforts to reduce emissions.

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Planning and Building Large Scale Projects in the United States: California High-Speed Train Project Case Study

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ABSTRACT

In April 2009, President Obama outlined a vision for investment in an efficient network of high-speed intercity passenger rail services connecting major population centers from 100 to 500 miles apart. The US Department of Transportation (USDOT) is working in partnership with individual states to plan and develop these high-speed and intercity passenger rail corridors that range from upgrades to existing services to entirely new rail lines exclusively devoted to 150 to 220 mph trains. This program of investments in rail transportation is a large scale undertaking only matched in scope by the building of the interstate highway system.

The Dwight D. Eisenhower System of Interstate and Defense Highways took over 30 years to be substantially completed. The highway building program benefited in the early years of its development from general political consensus, substantial federal involvement and partnership with the states and the vocal and active advocacy of the program by President Eisenhower and all subsequent Administrations. Similarly, the true potential of a fully integrated high-speed intercity passenger rail network will not be achieved unless the same political consensus, federal-state partnerships, dedicated funding and active involvement by President Obama and future Presidents is realized.

This paper explores the planning protocols, environmental regulations and political challenges facing high-speed rail program development in the United States by examining the experiences and sharing insights gained by two senior project managers working on the California high-speed rail project.

It is concluded that the building of a true network of high-speed rail services in the United States has been unable to replicate the extraordinary achievement of the interstate highway system in the same time frame because of statutory and regulatory environmental requirements and the lack of political will and consensus.

HISTORICAL ACHIEVEMENT OF THE U.S. INTERSTATE HIGHWAY PROGRAM

The United States of America has realized a high level of economic development as the result of investment in large infrastructure projects funded by the public treasury in partnership with local government and private interests. Probably the greatest public works project achievement in the history of the United States was the construction of the Dwight D. Eisenhower System of Interstate and Defense Highways. Over 46,000 miles of limited access interstate highways have been constructed since the signing of the *Federal-Aid Highway Act of 1956*. What most people fail to remember about this achievement is that the majority of the planning, design and construction of the interstate highway system occurred prior to the passage of the National Environmental Policy Act of 1969 (NEPA).

Planning and Construction of the Interstate Highway System

The planning for the national system of superhighways started under the Administration of President Franklin D. Roosevelt (FHWA 2011). The first formal inquiry into the possibility of building an interstate highway system goes back to Section 13 of the Federal Highway Act of 1938 which states:

> "The Chief of the Bureau of Public Roads is hereby directed to investigate and make a report of his findings and recommend feasibility of building, and cost of, super highways not exceeding three in number, running in a general direction from the eastern to the western portion of the United States, and not exceeding three in number, running from the northern to the southern portion of the United States, including the feasibility of a toll system on such roads."

The report prepared by the Bureau of Public Roads found the construction of such roads were feasible and recommended that the President appoint a commission to study the need for the national system of interregional highways. In April 1941 President Roosevelt appointed a committee, known as the National Interregional Highway Committee "to investigate the need for a limited system of national highways...to advise the Federal Works Administrator as to the desirable character of such improvement…:"

Much of the planning and discussion of the interregional highway system was muted by the war effort after the United States entered World War II in December 1941, but the National Interregional Highway Committee continued its work. In January 1944, President Roosevelt transmitted the National Interregional Highways Report to the Congress (Roosevelt 1944). The report recommended a 33,920-mile system of interregional limited access highways. A House bill under consideration at that time already had a 40,000-mile system defined for hearing purposes. The report also recommended that the program begin in the cities and work outward since that was where the greatest need for traffic congestion relief existed.

After a series of Congressional hearings on the report, Congress passed the *Federal-Aid Highway Act 1944*, which for the first time specifically earmarked funds for the "federal-aid highway system" and encouraged cooperation between the federal government and states in developing an integrated network of interregional highways.

Little activity in advancing the highway program occurred from the end of World War II through the end of the Korean War. Planning for the interregional highway system continued, but realized little progress with limited funding or resources due to the war efforts. In 1954, President Dwight D. Eisenhower reinvigorated the discussion of a national system of highways. As Supreme Commander of Allied Forces in Europe during World War II, he had recognized the importance of a system of interconnected superhighways for economic development and defense purposes after experiencing how the *Autobahn* system supported military operations of the German Army in the European theater of operations. He called for a "Grand Plan" for highways extending over a ten-year period and asked the governors for their help in achieving this vision.

The planning of the interstate highway system was driven by the publication in 1955 of the *General Location of National System of Interstate Highways* (AJFROGGIE 2011), informally known as the "Yellow Book." The Yellow Book was comprised of a series of maps showing generalized alignments through and around major cities that comprised 43,000 miles of freeways. After a series of hearings in 1955 and early 1956, the *Federal-Aid Highway Act of 1956* was enacted by Congress and signed into law by President Eisenhower. This act outlined the system of interstate of highways that followed the Yellow Book series of highway maps, providing a blueprint to guide the project implementation that would occur over many years.

Highway engineers drove the specific project level alignment decisions often without regard to the cohesiveness of neighborhoods or other environmental considerations. By 1966, more than half of the originally planned interstate highway system was open to traffic and by the early 1970s most of it was substantially complete (FHWA 2011). Authorized expansions since then have added mileage to the original system, which now is comprised of over 46,000 of limited access freeways.

Concerns Regarding Environmental Impacts

Prior to the 1960s, little formal consideration was given to the potential impact of human activity on the environment when major infrastructure projects were being planned and constructed. This was especially the case during the planning of the interstate highway system. Highway design and planning practices employed during the early development of the interstate highway system often divided neighborhoods or segregated districts in major cities, which were then separated by the impassible interstate highway right-of-way and its infrastructure. Many low income and minority population neighborhoods were especially impacted by the highways constructed in the heart of urbanized areas of the country. Citizens in many cities protested the alignment decisions and the disruption caused by freeway location decisions and the impacts on historic properties and neighborhoods (FHWA 2011).

This community disruption aided the growing environmental and civil rights movements emerging in the late 1950s and early 1960s. What began as reactions of the people directly affected by the disruption of massive highway projects on neighborhoods and communities united civil rights activists, environmentalists, urban neighborhood preservationists, and downtown business groups. This led to the passage of the National Historic Preservation Act of 1966 and the inclusion of Section 4(f) in the Department of Transportation Act of 1966, which protects historic and other cultural resources.

The environmental movement grew in intensity with the publication of *Silent Spring* by Rachel Carson, which was published in September 1962. The book was widely read and incited public concerns regarding the specific use of pesticides and the pollution of the environment in general. The book also inspired others to begin questioning the overall impacts of public infrastructure projects on the natural environment and to be concerned about air and water quality. Finally, when the highly polluted Cuyahoga River caught on fire in Downtown Cleveland in the summer of 1969, the Congress finally was moved to act (Scott, 2009).

THE NATIONAL ENVIRONMENTAL POLICY ACT

The National Environmental Policy Act of 1969 (NEPA) was signed into law by President Richard M. Nixon on January 1, 1970. NEPA declared a national policy to protect the environment and created a Council on Environmental Quality (CEQ) in the Executive Office of the President. To implement the national policy, NEPA required that a detailed statement of environmental impacts be prepared for all major federal actions significantly affecting the environment. The “detailed statement” would ultimately be referred to as an environmental impact statement (EIS). NEPA effectively changed the process for planning and implementing major infrastructure projects.

With an initial absence of regulations specifying implementation procedures and no agency authorized to enforce the law, litigation began almost immediately to interpret NEPA’s requirements and enforce federal agency compliance. In addition to questions of procedure, another question was how the environmental policy goals of the act should be implemented or enforced. The courts ultimately decided that NEPA is a procedural statute with two primary goals:

1) Agencies must consider the environmental impacts of their proposed actions before proceeding with the project, and
2) Agencies must inform the public that environmental concerns have been considered in their decision-making process.

In that capacity, NEPA has become a primary mechanism for public participation in the federal decision-making process. In the more than 30 years since passage of NEPA, Congress has amended the law only to include minor technical changes. The essential characteristics of the regulatory framework are discussed below.

Environmental Regulations

The CEQ issued regulations implementing NEPA in late 1978. These regulations became effective and binding upon most federal agencies on July 30, 1979, and for all remaining federal agencies on November 30, 1979. The *Regulations for Implementing the Procedural Provisions of the National Environmental Policy Act* (40 CFR 1500 – 1508) authorizes EIS documents to be prepared in stages, often referred to as "tiering." Tiering addresses broad programs and issues in initial or programmatic level analyses (Tier 1) and then analyzes project level site-specific alternatives and impacts in subsequent (Tier 2) studies. The tiered process is intended to support decision-making on issues that are ripe for decision and provides a means to preserve those decisions.

At the time the regulations were being promulgated, commenters complained that the tiering process added another legal requirement and layer of regulatory approval. However, the CEQ responded to the comments in the Final Rule:

> *Tiering does not add an additional legal requirement to the NEPA process. An environmental impact statement is required for proposals for legislation and other major Federal actions significantly affecting the quality of the human environment. In the context of NEPA, "major Federal actions" include adoption of official policy, formal plans, and programs as well as approval of specific projects, such as construction activities in a particular location or approval of permits to an outside applicant. Thus, where a Federal agency adopts a formal plan which will be executed throughout a particular region, and later proposes a specific activity to implement that plan in the same region, both actions need to be analyzed under NEPA to determine whether they are major actions which will significantly affect the environment. If the answer is yes in both cases, both actions will be subject to the EIS requirement, whether tiering is used or not. The agency then has one of two alternatives: Either preparation of two environmental impact statements, with the second repeating much of the analysis and information found in the first environmental impact statement, or tiering the two documents. If tiering is utilized, the site-specific EIS contains a summary of the issues discussed in the first statement and the agency will incorporate by reference discussions from the first statement. Thus, the second or site-specific statement, would focus primarily on the issues relevant to the specific proposal, and would not duplicate material found in the first EIS. It is difficult to understand,*

> *given this scenario, how tiering can be criticized for adding an unnecessary layer to the NEPA process; rather, it is intended to streamline the existing process* (Federal Register 1978).

Many federal agencies embraced the concept of tiering. This included the Federal Highway Administration (FHWA) and the Federal Railroad Administration (FRA). In particular, the FRA has preferred to use a tiered approach to the preparation of EIS documents to make broad program decisions for large expansive transportation corridors that are too big to be addressed in detail in one EIS document, are phased over time, include future phases that are not fully defined, or require evaluation of major routing or service alternatives. The FRA revised its *Procedures for Considering Environmental Impacts* in 1999 to correct inconsistencies with the CEQ National Environmental Policy Act implementing regulations, and to improve public access to the process that governs FRA's compliance with NEPA and related environmental and historic preservation laws and regulations. FRA issued additional guidance on the preparation of "Service NEPA" (Tier 1) and "Project NEPA" (Tier 2) documents in August of 2009.

Legal Precedent and Interpretation of Regulatory Requirements and Guidance

The courts have addressed tiering in several cases involving NEPA studies for highways and other linear projects. The case law recognizes that tiering is a valid approach for complying with NEPA, particularly for large-scale and complex plans, programs, and projects. The case law also recognizes that a Tier 1 EIS can be completed for a single large project, followed by a series of smaller-scale NEPA studies for individual sections or components of that project. The case law underscores the importance of considering NEPA and non-NEPA requirements when conducting a tiered study (Parsons Brinckerhoff, 2009).

There is one recent case (LEXIS 2007) where the court considered the issue of tiering in detail and concluded that the level of detail in the Tier 1 EIS was appropriate:

> *Tiering allows agencies contemplating projects of massive scope to sort through broad and far-reaching issues in an initial phase before expending the resources needed for more exacting determinations such as preparing engineering plans and acquiring rights-of-way in later phases…*

The court went on to say:

> *…the choice to analyze the impacts of such a large project in tiers was not arbitrary or capricious. If every major federal action required the level of analysis proposed for the second tier for every alternative considered, public works could too easily grind to a halt and become hopelessly mired in their own bureaucracy…. The*

art of effective tiering is to find the appropriate depth of detail at each level.

The court also noted tiering "does not come without significant risk." The court cited several potential risks in a tiered process including:

- *Environmental impacts that appear to be tolerable and potentially manageable in the first tier may emerge as unacceptable threats to affected species and ecosystems during the more detailed scrutiny in the second tier. But after federal and state agencies conduct more detailed field studies along the ...corridor and the agencies must face more detailed decisions about a more precise route, those impacts may or may not turn out to be acceptable.*

- *It is possible, although not probable given the information available; that ... may have to return to the drawing board and reconsider previously rejected alternatives to achieve their goals. That possibility is, however, a risk inherent in, and not an abuse of, tiering.*

In other words, tiering poses the risk of extending the time it takes to make project level decisions, especially regarding exact alignment. Tiering also opens the environmental review process to multiple opportunities for public and agency comment. The environmental review process also requires review and compliance with other laws enacted to protect the environment, which may change after programmatic decisions have been adopted.

Protection of Cultural Resources

The National Historic Preservation Act of 1966 (NHPA) requires Federal agencies to take into account the effects of their undertakings on historic properties, and afford the Advisory Council on Historic Preservation (ACHP) a reasonable opportunity to comment. The historic preservation review process mandated by NHPA Section 106 is outlined in regulations issued by ACHP. Revised regulations, "Protection of Historic Properties" (36 CFR Part 800), became effective January 11, 2001.

The Department of Transportation Act of 1966 (DOT Act) included a special provision in Section 4(f) that protects public land from acquisition for transportation uses. DOT agencies cannot approve the use of land from publicly owned parks, recreational areas, wildlife and waterfowl refuges, or public and private historical sites unless there is no feasible and prudent alternative to the use of land and the action includes all possible planning to minimize harm to the property resulting from use. Often the determination of feasible and prudent alternatives results in detailed studies of avoidance and impact minimization along with analysis of potential mitigation measures, which may add time to the environmental evaluation.

Clean Air Act

Congress passed the original Clean Air Act (CAA) in 1963 and added Section 309 in December 1970 to further clarify agencies' responsibilities with regard to public involvement in the NEPA process. That same year Congress also created the EPA and gave it the primary role in carrying out the revised law. Since 1970, EPA has been responsible for a variety of CAA programs to reduce air pollution nationwide. In 1990, Congress dramatically revised and expanded the CAA, providing EPA even broader authority to implement and enforce regulations reducing air pollutant emissions (EPA 2012).

Provisions of Section 309 of the CAA made explicit that the Administrator of the newly formed Environmental Protection Agency (EPA) has a duty to examine and comment on all EIS documents. After that review, the Administrator was directed to make those comments public and, if the proposal was environmentally "unsatisfactory," to publish this finding and refer the matter to the CEQ. EPA subsequently developed a program for reviewing and rating federal agency projects.

Clean Water Act

The Clean Water Act (CWA) establishes the basic structure for regulating discharges of pollutants into the waters of the United States and regulating quality standards for surface waters. The basis of the CWA was enacted in 1948 and was called the Federal Water Pollution Control Act, but the Act was significantly reorganized and expanded in 1972. "Clean Water Act" became the Act's common name with amendments in 1977. Under the CWA, EPA has implemented pollution control programs such as setting wastewater standards for industry. EPA also sets water quality standards for all contaminants in surface waters (EPA 2011).

The CWA made it unlawful to discharge any pollutant from a point source into navigable waters, unless a permit was obtained. EPA's National Pollutant Discharge Elimination System (NPDES) permit program controls discharges. Point sources are discrete conveyances such as pipes or man-made ditches. Individual homes that are connected to a municipal system, use a septic system, or do not have a surface discharge do not need an NPDES permit; however, industrial, municipal, and other facilities must obtain permits if their discharges go directly to surface waters.

Section 404 of the CWA establishes programs to regulate the discharge of dredged or fill material into waters of the United States, including wetlands. Activities in waters of the United States regulated under this program include fill for development, water resource projects such as dams and levees, infrastructure development such as highways and railroads and mining projects. Section 404 requires a permit before dredged or fill material may be discharged into waters of the United States, unless the activity is exempt from Section 404 regulation (e.g. certain farming and forestry activities). Individual permits are reviewed by the U.S. Army Corps of Engineers, which evaluates applications under a public interest review, as well as the environmental criteria set forth in the guidelines established in CWA Section 404.

Fish and Wildlife Coordination Act

It is generally acknowledged that the first major federal wildlife statute to employ the strategy of compelling consideration of wildlife impacts was the Fish and Wildlife Coordination Act of 1934 (FWCA) (Bean 1983). Its enactment pre-dates much of the current body of environmental law, including the National Environmental Policy Act.

The FWCA represents one of the earliest and most significant indications of the intent of Congress that fish and wildlife considerations were to be a major component of the analysis of projects affecting bodies of water and were to receive equal consideration with other traditional project purposes such as navigation and flood damage reduction. Because of its wide applicability to water resource development projects, it has often been referred to as "umbrella" authority for the involvement of the U.S. Fish and Wildlife Service (FWS) in project planning (Smalley 2004). FWS and National Marine Fisheries Service evaluates impacts on fish and wildlife of all new federal projects and federally permitted projects, including projects subject to the requirements of Section 404 of the CWA.

Endangered Species Act

The Endangered Species Act of 1973 (ESA) provides a program for the conservation of threatened and endangered plants and animals and the habitats in which they are found. The lead federal agencies for implementing ESA are the U.S. Fish and Wildlife Service (FWS) and the U.S. National Oceanic and Atmospheric Administration (NOAA) Fisheries Service. The FWS maintains a worldwide list of endangered species. Species include birds, insects, fish, reptiles, mammals, crustaceans, flowers, grasses, and trees.

The law requires federal agencies, in consultation with the U.S. Fish and Wildlife Service and/or the NOAA Fisheries Service, to ensure that actions they authorize, fund, or carry out are not likely to jeopardize the continued existence of any listed species or result in the destruction or adverse modification of designated critical habitat of such species. The law also prohibits any action that causes a "taking" of any listed species of endangered fish or wildlife (EPA 2011).

Consequences of Regulatory Process

Most of these statutes and implementing regulations were not in effect for the first 10-12 years of the interstate highway program when nearly half the system was built.
The federally funded projects being built today must have an environmental impact statement that take into account the impact of the project on air and water quality and the natural and built environment. This often requires considerable study of ecosystems and the habitat and migratory patterns of species.

The impact of these environmental statutory and regulatory changes in transportation project development have lengthened the time it takes to move a project from concept to environmental clearance and permitting to design, construction and operation. The California High-Speed Rail Project will be examined to illustrate the length of time it takes to move through the environmental review and approval process.

CALIFORNIA HIGH-SPEED TRAIN PROJECT

The Passenger Rail Investment and Improvement Act of 2008 (PRIIA) required Amtrak, the U.S. Department of Transportation (US DOT), Federal Railroad Administration (FRA), States, and other stakeholders to begin improving intercity passenger rail service, operations, and facilities. PRIIA focused on Amtrak's long-distance routes and the Northeast Corridor (NEC), state-sponsored corridors throughout the country and the development of high-speed rail corridors. Just as the Yellow Book provided guidance that helped realize the 46,000-mile Interstate Highway system, PRIIA aimed to define a multi-state vision for passenger rail across the U.S.

With PRIIA as a backdrop, President Barack Obama announced plans in April 2009 for the development of a high-speed rail network connecting major cities that house 80 percent of the country's population. President Obama pledged $8 billion in high-speed rail program funds set aside from the $787 billion stimulus funding package. States were invited to identify and propose the development of high-speed rail corridors, which would be funded on a competitive basis.

One of the most ambitious state-sponsored high-speed rail programs in the United States is the 800-mile high-speed train project in California designed to link San Diego, Los Angeles, and the cities of the Central Valley to San Jose, San Francisco and Sacramento.

Planning for the California High-Speed Rail Project

Planning for the proposed California High-Speed Train Project had begun years earlier. In 1993, the California State Legislature created the California High Speed Rail Commission to study the feasibility of a high-speed rail (HSR) system connecting the southern part of the state with the Bay Area and Sacramento, with particular emphasis on connecting Los Angeles with San Francisco. The objective of the study was to determine the viability of HSR as an alternative to congested highways and airways in the state. The preliminary feasibility study completed in 1998 cautiously concluded that HSR can work in California but to be successful, the system would require travel times and passenger fares that were competitive with air travel between the Bay Area and Los Angeles (CHSRA 2011).

Senate Bill 1420 created the California High Speed Rail Authority (CHSRA) to replace the Commission at the conclusion of the feasibility study in 1998. The

CHSRA was directed to finalize a system plan (route, technology, and funding) and to undertake final engineering and implementation. Since then, the CHSRA has embarked on a series of activities designed to fulfill the mandate of the State Legislature to implement high-speed train service on the 800-mile system linking San Diego, Los Angeles and the cities of the Central Valley with San Jose, San Francisco and Sacramento.

Following adoption of a Final Business Plan in 2000, the CHSRA recommended the state proceed with implementation of a statewide high-speed train system by initiating the formal state and federal environmental review process through the preparation of a state program level Environmental Impact Report (EIR) in compliance with the California Environmental Quality Act (CEQA) and a federal Tier I Environmental Impact Statement (EIS) in compliance with NEPA. Although NEPA and CEQA are similar in scope, there are regulatory differences that require additional analyses and documentation to satisfy both federal and state processes.

Program Level Environmental Impact Report/Statement (Tier 1 EIR/EIS)

The program level EIR/EIS commenced when the state Notice of Preparation of an EIR was issued on April 6, 2001 and the federal Notice of Intent to prepare a Tier 1 EIS was published in the *Federal Register* on May 2, 2001. As part of the Program EIR/EIS, a number of project alternatives were evaluated including a No Project Alternative and a High-Speed Train Alternative. Within the High-Speed Train Alternative, there was a range of high-speed train alignment and station location options to be considered. The purpose of the program level High-Speed Train Alignments/Stations Screening Evaluation was to consider all reasonable and practical options within the various defined corridors at a consistent level of analysis and focus the Program EIR/EIS on those alignment and station options that best attain the objectives established by the CHSRA. Intended outcomes of the Tier 1 analysis included adoption of preferred HSR corridors and station locations, which would be subject to refinement during Tier 2, project specific environmental analysis.

Notice regarding the availability and the circulation of the Draft Program EIR/EIS was provided pursuant to CEQA and NEPA requirements. The Draft Program EIR/EIS was released for public review and comment on January 27, 2004 and noticed in the *Federal Register* on February 13, 2004. The initial public comment period was scheduled to end May 14, 2004, but due to public requests, was extended to August 31, 2004. During the Tier 1 environmental process, CHSRA solicited public and stakeholder input through 15 town hall meetings attended by nearly 1,000 people, 17 formal scoping meetings, interagency consultation with 27 interested state and federal agencies, as well as a number of briefings and discussions with other federal and state agencies and regional jurisdictions. Formal testimony was received on the Draft Program EIR/EIS at seven public hearings and through nearly 2,000 letters, postcards, and website postings. Responsible agency and public oral and written comments submitted by August 31, 2004 were addressed and responded to in the Final Program EIR/EIS.

The CHSRA and the FRA completed a Final Statewide Program EIR/EIS in August 2005 as the first phase of a tiered environmental review process for the proposed California High-Speed Train (HST) system four years after the initial scoping meetings were held in May 2001. Through a comprehensive screening evaluation covering many regions of the state, numerous alignment and station options were identified and selected for analysis in the Program EIR/EIS. The preferred HST alignment and station locations best met the objectives and criteria for minimizing potential environmental impacts while maximizing HST ridership potential and connectivity and accessibility. Stations were to be located in the central business districts where appropriate. These alignment and station options were to be the focus of future project-specific analysis.

Within California's Central Valley, the potential HST impact on agricultural lands was of particular interest and focus in evaluating environmental effects. The Central Valley is one of the most active agricultural regions in the United States (Struglia 2003). The program level EIR/EIS estimated that right-of-way requirements of the HST Alternative, based on the system-wide application of the proposed high-speed train right-of-way, could potentially impact 2,445 to 3,860 acres of prime farmland. When viewed in the context of the overall trend of farmland loss in California of 49,700 acres per year (or nearly 845,000 acres projected to be lost to development by 2020), the right-of-way needs of the HST Alternative represented less than 0.4 percent of the state's total potential farmland loss over the planning horizon. Furthermore, the indirect effect of the HST Alternative on urban growth was estimated to avoid the loss of 4,100 acres of farmlands as compared to the No Project Alternative on a statewide basis by 2035 due to more focused urban development around HSR stations (CHSRA 2005).

The CHSRA made a serious commitment to utilize existing transportation corridors and rail lines to minimize the impacts on California's agricultural and cultural resources. Another key objective was to avoid and/or minimize the potential impacts wildlife refuges and habitat. The use of HSR alignments adjacent to existing railroad alignments and highways was aimed to avoid bifurcation of farmlands, to reduce affects on wildlife and migratory patterns, and to connect to existing urban centers while limiting sprawl effects that could be associated with a greenfield approach. This commitment to utilize existing transportation corridors would later prove to be challenging in the project level EIR/EIS.

The preferred HST Alternative adopted by the HSRA for Central Valley after the program level analysis included an alignment roughly paralleling the BNSF corridor between Merced and Bakersfield, with potential HSR stations at either the decommissioned Castle Air Base in Merced or downtown Merced, in downtown Fresno, and in downtown Bakersfield near the existing Truxtun Amtrak Station. (CHSRA 2005). This alignment was determined at the program level to have lesser constructability challenges and cultural resource and property impacts than other options considered; however, a greater potential for significant impacts to wetlands and biological species and habitats were identified.

The CHSRA and FRA completed a separate second program EIR/EIS in July 2008 to identify a preferred alignment for the Bay Area to Central Valley segment of the 800-mile HST system. The Bay Area to Central Valley HST Program EIR/EIS resulted in a decision by the CHSRA and FRA to connect the Bay Area and the Central Valley through the Pacheco Pass and to proceed along the Caltrain rail right-of-way from San Francisco to San Jose. In August 2008, the Town of Atherton and others challenged the adequacy of the Bay Area to Central Valley Program EIR/EIS for its compliance with CEQA. The final judgment in the case upheld the Program EIR in many respects, but required additional work in some areas to comply with CEQA.

Nearly a decade after the program level environmental work had begun, the CHSRA circulated a Revised Draft Program EIR in March and April 2010, prepared responses to comments, and then issued a Revised Final Program EIR in August 2010.
Program level environmental analysis identified the general differences in potential environmental consequences between the No Project and the various HST Alignment Alternatives within each study region. Based upon the tiered approach to NEPA, the Revised Final Program EIR supported the selection of preferred alignments and station locations that were certified by the CHSRA Board in September 2010. This decision-making is intended to allow for a more focused analysis of potential impacts of the preferred alternatives as a starting point for project level environmental analysis.

Project Level Environmental Impact Report/Statement (Tier 2 EIR/EIS)

With limited state funding available to advance the HST program, more than three years elapsed between completion of the Tier 1 EIR/EIS documents and commencement of the scoping process for the Tier 2 studies. Voter approval of a state bond issue for high-speed trains in 2008, along with the PRIIA-defined December 31, 2011 deadline for NEPA Notice of Decision and CEQA Record of Decision, renewed interest in advancing HSR planning in California.

An updated November 2008 Business Plan established a phased implementation plan that set forth individual timetables for completion of the environmental documents for each of the eight segments of the 800-mile HST system. The project level EIR/EIS for the Central Valley Merced–Bakersfield segment commenced on February 24, 2009, when a Notice of Preparation was distributed to the State Clearinghouse; elected officials; local, regional, and state agencies; and the interested public. A Notice of Intent was published in the *Federal Register* on March 16, 2009, notifying the public of FRA’s intention to prepare an EIS for the Merced to Bakersfield section of the HST System.

The CHSRA and FRA subsequently determined that the environmental impacts of the HST System from Merced to Bakersfield, comprising more than 160 miles of alignment, would be more appropriately assessed in two separate EIR/EIS documents, one from Merced to Fresno and another from Fresno to Bakersfield. A new Notice of Preparation and Notice of Intent for the Project EIR/EIS, amending the environmental process were issued on September 29, 2009, and October 1, 2009, respectively. Other segments of the HST system were noticed during a similar time frame.

As part of the CEQA/NEPA scoping process, the high-speed train alignment and station location options identified by the Tier 1 EIR/EIS documents in the Central Valley and elsewhere were used to initiate public and agency comment. During the Tier 2 scoping process, issues previously thought to be potentially manageable in the first tier study emerged as unacceptable threats to affected species and ecosystems during the more detailed scrutiny in the project level analysis. This included impacts to wetlands as well as community disruption caused by noise and vibration within the urbanized areas of the existing transportation corridors.

The need to acquire and widen existing transportation corridors to accommodate the HST system also severely impacted local communities necessitating elevating the high-speed rail line in many locations adding to the costs of building the system. In order to shorten the length of the line, reduce the cost of construction and minimize noise and vibration in the urbanized areas, several new alignments not studied in the Tier 1 documents were put forward for more detailed investigation. This essentially revisited and reopened the program level analysis and decisions.

One of the alignments put forward as not previously analyzed in the Tier 1 document was a “greenfield” alignment that cut diagonally across farmland plots that were oriented in north-south grids. Although this alignment was the cheapest to construct and had the fewest impacts to urbanized areas, the impacts to the individual farms were considered too severe by local stakeholders who lobbied the CHSRA Board successfully to consider other newer alternatives. In late 2009 and into 2010 a detailed analysis of several newer alternatives was initiated to select a preferred alternative to advance to detailed environmental analysis. A preferred “hybrid” alternative was selected by the CHSRA in 2010 (CHSRA 2010).

The Draft EIR/EIS document for the Merced – Fresno segment was completed and circulated for public review in July 2011, after nearly two and a half (2 ½) years of detailed technical analysis and considerable public outreach. The public comment period was closed on September 15, 2011. The CHSRA is documenting all comments received and preparing responses on the Draft EIR/EIS. The Final EIR/EIS for the Merced to Bakersfield sections are being prepared now and are planned for release in early 2012. The U.S. Army Corps of Engineers and the EPA have asked a series of questions related to the alternatives analysis process used to eliminate some alignment alternatives that appear to have fewer environmental impacts than the alternative recommended by the CHSRA.

EIR/EIS documents for other segments of the HST are also being completed at this time. A Revised Draft Environmental Impact Report (EIR)/Supplemental Draft Environmental Impact Statement (EIS) for the Fresno-to-Bakersfield section of the high-speed train project are scheduled to be released in spring 2012. This additional analysis of alternatives in the Fresno to Bakersfield section will not impact nor will it affect the Draft EIR/EIS for the Merced-to-Fresno section. Rather than issuing a Final EIR/EIS for the Fresno-to-Bakersfield section in January 2012 as previously scheduled, the CHSRA will now use the coming months to further engineer the additional Hanford West Bypass route and new station alternative, conduct the additional environmental analyses needed, seek value engineering opportunities to reduce costs, and make other necessary revisions including those based on comments received from the public and public agencies through October 13, 2011.

Records of Decision for these EIR/EIS documents will likely be obtained sometime during 2012 after over three years of study and engineering repeating many of the studies that were undertaken in the program level document simply because the public pays more attention to a project when it is more imminent.

Elapsed Time

The total elapsed time from the Notice of Intent of the Tier 1 program level EIR/EIS to the time of the expected Record of Decision for the Tier 2 project level EIR/EIS in the Central Valley is expected to be more than 11 years! -As a point of comparison, nearly half of the interstate highway program was constructed between the passage of the *Federal-Aid Highway Act of 1956* and the passage of the NHPA and Transportation Act in 1966 when federal and DOT agencies were required to begin evaluating the impacts of their projects on historic and cultural resources. With the passage of NEPA and related environmental protection law in the early 1970s, the time it took to complete the rest of the interstate system became longer.

Further, the tiered environmental process, which was intended to facilitate project decision-making and allow programmatic actions such as right of way preservation and land use planning to move forward, has not succeeded in achieving those desired outcomes. Rather, each decision and analysis performed as part of the program level EIR/EIS needed to be revisited during the project level EIR/EIS.

OTHER CONSIDERATIONS

The length of time to complete planning, environmental approval, permitting, design and construction of large infrastructure projects usually also spans several Presidential and Gubernatorial administrations along with varying terms of Congress and state legislatures. The interstate highway program enjoyed bi-partisan support for the passage of the Federal Aid Highway Act of 1956 and support that continued over the three decades to build out the system. The intercity passenger and high-speed rail program does not enjoy such broad support. In fact, the annual appropriation process for the National Railroad Passenger Corporation (Amtrak) has become a political issue in partisan squabbles about fiscal responsibility and the role of Government.

Since the creation of Amtrak in 1971 under the Administration of President Richard M. Nixon, several Presidents have tried to zero out Amtrak's operating budget citing the need to eliminate continuing federal subsidies and questioning the role of government ownership and operation of intercity passenger trains. Arguments about the role of Government operating trains are reminiscent of the debates on the federal role in building and maintaining an interstate highway system during the 1930s and 1940s.

In today's highly-charged partisan political atmosphere, it is not uncommon for investment decisions made by one Gubernatorial Administration to be reversed by the next incoming Administration. In well publicized reversals of established public policy, the newly elected Governors of Florida, Ohio and Wisconsin reversed course on intercity passenger and high-speed rail development in their states by cancelling programs and returning the associated federal funding awarded to their states for those programs to the USDOT. Ever longer planning periods make major infrastructure programs increasingly susceptible to such political shifts over time.

In addition, the process orientation and public participation element of NEPA has also spawned a cottage industry of law firms that specialize in NEPA litigation on behalf of litigants who oppose projects. With NEPA requiring substantive public involvement and comment on the EIS documents prepared by states and local agencies for the federal sponsoring agency, the balance of power seems to have shifted from state transportation planners and engineers to community activists.

There are well organized and funded special interest groups who oppose urban and intercity passenger and high-speed rail projects on the basis of political philosophy. It is the intent of these groups to stall or call into question the assumptions and results of the numerous studies undertaken to satisfy the NEPA process or local requirements such as CEQA and the California requirement for the CHSRA to prepare and regularly update business plans.

The shifting of the balance of power from state transportation planners to community activists and special interest groups has effectively lengthened the time required to achieve informed political decision. And often, many of the consensus decisions are made for politically expedient reasons to advance projects and minimize the threats of nuisance lawsuits designed to thwart progress and cause costs to escalate to levels that no longer support positive benefit/cost ratios contained within business plans. And even after a consensus decision has been made, a change in Administrations may reverse prior political decisions further delaying or cancelling projects. The interstate highway program did not suffer from these underlying conditions in its early years of development. But the intercity passenger and high-speed rail program does.

Organized Opposition to the High-Speed Rail Program

Several studies prepared by the Volpe Transportation Center of the USDOT and the Government Accountability Office (GAO) have inflamed the political debate by questioning the viability of rail investments generally and high-speed in particular.

A report was prepared by the Volpe Transportation Center in 1989 (Pickrell 1989) for what is today's Federal Transit Administration (FTA) to evaluate urban rail projects and make recommendations on forecasting and planning techniques to improve the federal funding and selection process. This study became known colloquially as the Pickrell Report.

As a backdrop to the study, there was a concerted effort by some conservative legislators and the Reagan Administration in the 1980s to kill the urban rail New Start program and to zero out Amtrak's budget. The Pickrell Report was prepared specifically to provide ammunition for those opposed to urban rail transit investments although the explicit objective of the report was for other purposes. However, critics of the New Start program used the report to evaluate whether investment in urban rail systems by the federal government should be made or not. The report showed that every New Start urban rail system built in the 1980s cost more than was budgeted and had ridership far below projections. These findings were cited by anti-rail activists as proof that urban rail transit was a poor investment.

Subsequent to the publication of the Pickrell Report, there was a substantial effort by the Cascade Policy Institute, Cato Institute, The Public Purpose, Buckeye Institute, the Heritage Foundation, the American Highway Users Alliance and others to send a cabal of rail opponents around the country to exploit the Pickrell Report's findings (CFTE 2011). Every city proposing a New Start rail program had to deal with these speakers, all of whom cited the Pickrell Report and all concluded that rail transit investment was not justified.

The Pickrell Report was criticized and discredited because it simply reviewed ridership forecasting and cost estimating in the early stages of project planning and compared these early estimates with construction costs and ridership a few years after the systems were opened. The Portland light rail transit project was used to illustrate how the Pickrell Report targeted early, outdated documents for criticism and ignored the actual decision matrices of local decision makers and compounded the misrepresentation by the choice of inappropriate comparison years. It was shown how the use of readily available data on boardings and operating costs for the various projects, instead of reconfigured data, would have warranted different conclusions from those expressed in the Pickrell Report.

The GAO prepared a report in 2009 entitled "*High Speed Passenger Rail: Future Development Will Depend on Addressing Financial and Other Challenges and Establishing a Clear Federal Role" The* GAO report says:

> *Rider forecasts and cost estimates are inherently uncertain and subject to some degree of inaccuracy simply because they are trying to predict future circumstances. However, analyses and research on the accuracy of rider forecasts and cost estimates for rail infrastructure projects have found that a systematic problem and incentive to be optimistic may exist—that is, actual riders are more likely to be lower than forecasted, while actual costs are more likely to be higher than estimated.*

The GAO Report cites the same discredited studies of 1980s urban rail transit projects, European rail projects and uses language identical to the Pickrell Report from 1989 to describe the "optimism bias" in feasibility studies without acknowledging the extraordinary efforts to remove this bias in contemporary study results. And, as we find, Don Pickrell was consulted by the GAO in the preparation of its report. According to the Pickrell Report:

> *...the systematic tendency to overestimate ridership and to underestimate capital and operating costs introduces a distinct bias toward the selection of capital-intensive transit improvements such as rail lines.*

Those words were first written in 1989 and are eerily similar to the GAO Report prepared in 2009.

The GAO study (and Pickrell in1989) did not look at the ridership forecasting model assumptions or test the forecasting protocols by changing the model assumptions and then seeing if the revised model results in a more accurate forecast. It simply looked at an early forecast and then reported actual ridership. Forecasts are based on future year conditions; a new system needs time to mature and grow into its future year forecast. One of the examples often cited is the English Channel Tunnel project and operation of EuroStar high-speed trains linking London, Brussels and Paris. At first glance, the EuroStar forecast looks optimistic when compared to actual ridership for the first several years of operation. The ridership forecast assumed the British would build its segment of the high-speed rail line connecting St Pancras Station in Downtown London with the Tunnel. The EuroStar trains started operating in the Tunnel in 1994 but the British high-speed rail line segment between the Tunnel entrance on the English Coast and St Pancras Station was not completed until 2007, thirteen years later than originally planned. As would be expected, the lack of this important system link resulted in EuroStar ridership was significantly less than had been forecasted for the first 13 years of operation without the segment in place.

Shifting Political Climate

Today the Obama Administration's high-speed rail program is undergoing intense scrutiny by a wary Congress. The GAO Report and the subsequent political strategy repeat the themes and schemes of the 1990s where the same cabal of rail opponents is sent around the country to exploit the GAO Report's findings. Special interest groups, notably highway road builders and other related lobbyists, have funded research aimed to discredit the economic rationale for investment in intercity passenger and high-speed service improvements.

Recent Congressional hearings chaired by Congressman John Mica (R, Florida) seem to cast a pall on the President's ambitious vision especially in light of the Congress not appropriating any additional funding to the high-speed rail initiative in Fiscal Year 2012. Mica declared at the start of a four-hour special hearing on the high-speed rail program that "The California project is turning out to be an additional disaster in a long list of projects touted for high-speed rail". Congressional representatives who were not supportive of PRIIA and its associated federal investments escalated their case against the California HST with calls for an independent audit by a nonpartisan watchdog agency. Some Congressmen formally requested a review of the California HST program by the GAO. In particular, the congressional skeptics want a closer look at California's ridership and cost projections.

In California, the high-speed rail program is coming under intense scrutiny locally as a newly released Business Plan was reviewed by the public and as project level EIR/EIS documents are finalized with recommended alignments. A recent report of the Legislative Analyst's Office took aim at the 2012 Business Plan finding it lacking in specifics on funding and questioning the reliability of ridership forecasts and cost estimates, themes enumerated in the prior GAO Report.

The ridership projections developed by CHSRA have been called into question by the University of California's Institute of Transportation Studies. In their report they write: "However, the combination of problems in the development phase and subsequent changes made to model parameters in the validation phase implies that the forecasts of high speed rail demand—and hence of the profitability of the proposed high speed rail system—have very large error bounds." (University of California, 2011).

Furthermore, the California High-Speed Rail Peer Review Group's November 2010 report raised a number of questions that collectively called into question the CHSRA's Business Plan. The Peer Review Group also noted "local opposition emerges when any route approaches finalization" in its report on the project. Not surprisingly then, the City of Palo Alto has passed a City Council resolution asking the Legislature to terminate the California high-speed rail project (Palo Alto On-Line News, 2012).

STATUTORY AND REGULATORY TRENDS

Congress has recognized that the length of time for environmental review and approval takes too long and has begun to streamline the environmental review process. In 2005, President George W. Bush signed into law the *Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users* (SAFETEA-LU).

SAFETEA-LU establishes a new environmental review process for transportation projects.

To enhance interagency coordination and ensure that issues of concern are identified, SAFETEA-LU creates a new category of involvement in the environmental review process termed "participating agency." The intent of the new category is to encourage governmental agencies at any level with an interest in the proposed project to be active participants in the NEPA evaluation. Designation as a participating agency gives invited agencies new opportunities to provide input at key decision points in the process, which is designed to identify concerns early in the study process so they can be addressed prior to publication of the EIS document.

SAFETEA-LU specifies that the lead agencies also must give the public the opportunity for involvement during the development of the purpose and need statement and the identification of the range of alternatives to be considered. Prior to SAFETEA-LU, the public scoping process typically included these elements of a NEPA review, but there was no explicit requirement to provide an opportunity for public involvement on purpose and need and on the range of alternatives in advance of the Draft EIS. As was seen in the California HST project, a wider array of alternatives was analyzed in the project level EIR/EIS than during the program level EIR/EIS adding time to the study process.

Environmental streamlining and stewardship requires transportation agencies to work together with natural, cultural, and historic resource agencies to establish realistic timeframes for the environmental review of transportation projects. These agencies then need to work cooperatively to adhere to those timeframes, while they are protecting and enhancing the environment. The efficient and effective coordination of multiple environmental reviews, analyses, and permitting actions is essential to meet the environmental streamlining and stewardship mandates for highway and public transportation projects under SAFETEA-LU.

Recently, the CEQ and USDOT announced a pilot program aimed at expediting the environmental reviews for high-speed passenger rail service in the Northeast Corridor through an innovative and more efficient process. Through this pilot project, CEQ and USDOT will engage federal, state and local governments and the public in the environmental review process earlier to set benchmarks that save time and costs by avoiding conflicts and delays in the later steps of rail-project development but still maintain rigorous environmental protections under existing law (Metro Magazine 2012).

The Northeast Corridor high-speed rail planning project is the fourth project selected by CEQ under its National Environmental Policy Act Pilot program, which focuses on identifying and promoting more efficient ways to do effective environmental reviews that can be replicated. CEQ will use efficiencies identified for the high-speed rail project to develop best practices for environmental reviews across the Federal Government.

CONCLUSIONS

Best practice in the planning phase of a project is defined as "a project that achieves a thorough environmental appraisal and public and political support within an efficient timescale". There are certain pre-requisites that must be in place, however, if this best practice is to be achieved. These pre-requisites include: (1) political will, (2) a project champion with good management and mediation skills, and (3) a defined source of funding or financing. If any of these measures are omitted and have to be brought in during the planning process then time costs are incurred (Pedler 2003).

The California high-speed rail program has been studied since the early 1990s culminating in a series of completed feasibility studies and business plans in 2000. Program level EIR/EIS documents were prepared and substantially completed in 2005. Project level EIR/EIS documents are just now being finalized in 2012 for a total elapsed time of 11 years for environmental clearance. This time spanned two Presidential Administrations, three Gubernatorial Administrations and several sessions of Congress and the General Assembly.

Continuing political opposition and lack of clear political consensus is hampering efforts to advance the California project beyond planning and environmental studies. As the project planning period lengthens, environmental analysis must be revisited to match updated regulatory requirements, to respond to new stakeholder demands, and to react to new funding realities. And so HSR program costs grow and implementation moves further into the future. Current Congressional efforts to thwart the ambitious national high-speed rail program envisioned by the Obama Administration casts doubt on the federal partnership needed by California and other states to advance individual HSR projects. Consequently, funding for the California HST project is not assured at either the state or federal level and recent resignations of the CHSRA Chief Executive Officer (Sacramento Bee 2012) and several key Deputies no longer provides continuity of key actors at the staff level. Changing Governors also adds to the uncertainty of political will.

Add to this political backdrop the unusually long tiered environmental analysis process often requiring the same alignments to be studied more than once, often at varying levels of detail, it is easy to conclude that development of an improved intercity passenger and high-speed rail system in the United States will take much longer to complete than the interstate highway program.

This added time for project planning and environmental approval also permits ample opportunity for groups to organize and voice opposition to alignments recommended in the environmental document delaying decisions and adding expense to the project both for litigation and escalation of construction and capital costs due to project delay.

In examining the timeframe of project implementation for TGV Eastern in France, total elapsed time from commencement of project planning to the completion of construction was 18 years. In France, project planning took eight years; Parliamentary approval took four more years with construction taking six years (Pedler 2003). The California HST program is still in the planning and environmental phase of project development after 19 years since the California General Assembly created the California High-Speed Rail Commission to study the feasibility of the system in 1993.

RECOMMENDATIONS

The environmental process should stress establishing clear decision points. In Europe, the decision process is tiered. In some European Union countries, the equivalent of a program level planning decision is enacted into law establishing a statutory decision in-principle to advance the project into implementation (Pedler 2003). This places the burden of building the business case and advocacy for the project in the program level planning phase. A decision by a Legislature enacting a law that approves a project cannot be overturned administratively by an incoming Governor. It would require an act of the Legislature to kill a project once approval has been enacted.

The clear focus of the project level implementation decisions are to examine and decide on detailed alignment and land-use within the framework of a project that has already been approved for implementation.

In the United States, the Record of Decision at the end of the project level EIS marks the end of project planning and the beginning of project implementation. However, all of the project review and approval process in the United States is administrative and does not carry the weight of statutory obligation so each of these earlier decisions can be reversed at any time. This opens the door for political partisans to change course because planning is never complete and decision in-principle to implement the project is never obtained. Approval to fund a project is not the same as approval in-principle to implement it. This needs to be changed.

It took almost three decades from the time President Franklin Roosevelt first conceived a national system of interregional highways until President Eisenhower signed the Federal Aid Highway Act of 1956 into law to achieve unprecedented bi-partisan support for building the interstate highway system. It will take considerably longer to achieve the same level of consensus regarding building a national system of intercity and high-speed trains.

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Danish Rail Infrastructure Modernization—Business Case for Mainline and Urban Networks

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ABSTRACT

The €3.2 billion Danish "Signalling Programme" is one of the largest railway modernization in the world to provide a total replacement of the signalling systems in Denmark [1]. This paper is focusing on the potential benefits to be delivered to the passengers, such as improved punctuality, increased capacity, by implementing advanced train control systems on both the main lines rail network (Fjernbane) and the Copenhagen suburban rail network (S-bane).

The main lines network will be fitted with the European standard train control system: ERTMS Level 2, while the Copenhagen S-bane network will be fitted with a Communication Based Train Control (CBTC) system using Automatic Train Operation (ATO).

This paper is also focusing on the possibility of implementing automatic driving operation (ATO) to the ERTMS level 2 solution for regional and high speed lines.

CBTC AND ERTMS OVERVIEW

CBTC and ERTMS are the latest generation of train control systems which are rapidly replacing conventional signaling systems all over the world and almost systematically implemented for new lines. This latest generation of train control systems uses less wayside equipment, bringing more intelligence onboard the trains and using radio based communication media to transmit signaling data between the trains and the wayside computers. Even though CBTC and ERTMS have similar architectures, they have been designed for different purposes. CBTC systems have been developed mainly to address capacity issues for metro type systems whereas ERTMS was designed as a standard system to address interoperability issues for cross-border service between European countries.

ERTMS system overview

ERTMS is an initiative started in the early 90s by the European railway industry to design interoperable train control systems in order to facilitate main line passenger and freight train movement from one country to another – eliminating the need for train operators and infrastructure managers to equip trains with multiple, national and legacy systems or switch locomotives at the borders. ERTMS is being offered in three different product levels with varying degrees of functionality:

- ERTMS Level 1, which provides a simple signal enforcement protection via a balise or a loop.
- ERTMS Level 2, which provides safe train separation and over-speed protection via movement authority information transmitted from the trackside to the train via GSM-R:

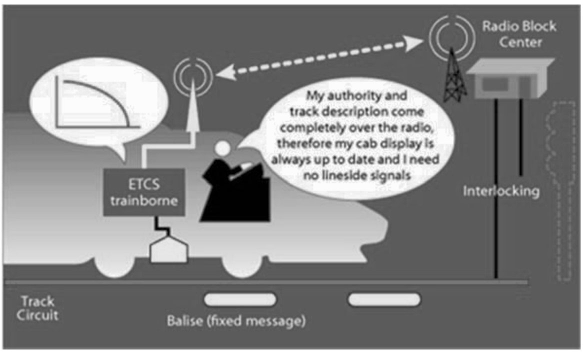

Figure 1: ERTMS Level 2 overview (ref.: www.ERTMS.net)

In theory, ERTMS level 2 would allow the removal of wayside signals as all the signaling information would be available onboard via a train driver display. It is noted, however, that ERTMS level 2 still uses the track circuits or axle counters for the train detection and for the train integrity monitoring function, unlike CBTC or ERTMS level 3 (see below).

The train position is calculated by the on-board equipment for speed and movement authority control

- ERTMS Level 3 is similar to ERTMS level 2 except that the train detection function does not rely on track circuits but on the position calculated by the onboard equipment (as with CBTC). The full version of ERTMS Level 3 is still in the development phase and has not been implemented yet.

CBTC system overview

CBTC systems have been developed mainly for metro type networks to improve capacity and safety. Unlike ERTMS, CBTC has not been designed to be interoperable. Each CBTC supplier provides a unique solution with similar performance and functionality. CBTC systems can be rolled-out as an overlay of an existing track-circuit based signaling system or as a complete stand-alone system with no or limited fallback.

By default, CBTC systems are supplied with a high level of automation such as automatic train operation (ATO) and automatic train supervision (ATS or Traffic Management System) providing advanced regulation functionalities. These features significantly enhance the flexibility of operations.

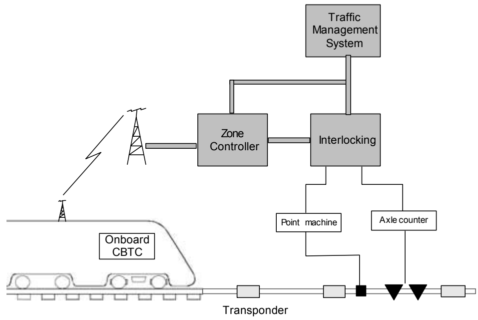

Figure 2: CBTC overview

The signaling industry (outside of the United States) shows a clear trend toward CBTC. Almost every transit agency in Europe and Asia chose to install CBTC to upgrade their signaling or when building new lines.

ERTMS and CBTC comparison

As discussed earlier, ERTMS and CBTC have been designed for different purposes. ERTMS is typically installed on main lines (regional, national networks) and CBTC on metro applications. For the purpose of this paper we are comparing CBTC with ERTMS level 2.

Table 1: CBTC and ERTMS comparison

Characteristics	CBTC	ERTMS L2
Architecture	Wayside, onboard, radio communication, fixed transmission and control center level (ATS)	Wayside, onboard, radio communication
Train detection	Via onboard equipment and balises	Via wayside equipment (track-circuits or axle counters)
Train/wayside communication	Proprietary or standard solutions, usually operating around 2.4 GHz or 5.8 GHz frequencies. Short transmission times.	One standard: GSM-R. Longer transmission times.
Level of automation	Included (ATO or fully driverless)	Not included in the standard solution. For some applications (Thameslink) an ATO layer is being developed.
Capacity / Headway performance	High. Can reach 30 TPH or higher.	Limited due to track-circuit train detection and GSM-R performance. Simulations show that with ATO, ERTMS Level 2 can reach 24 TPH in

Characteristics	CBTC	ERTMS L2
		certain cases.
Safety	High level of safety (safe train separation, continuous over-speed protection)	High level of safety (safe train separation, continuous over-speed protection)
Interoperability	None	Fully interoperable.
Reliability, Availability and Maintainability	High level of reliability, use of redundant architecture. Advanced diagnostics functionalities.	High level of reliability, use of redundant architecture.
Traffic Management System (TMS): regulation and supervision functions (ATS / CCR)	Advanced set of functionalities, included in the product.	Not included in the standard. Each application must interface with an existing TMS or develop its own.
Maturity of the available products	High	High
Main implementation risks	Depending on the application, the main risks are: - Too many changes in the standard product due to specific project requirements - Onboard integration longer than expected - Migration disruptive to the service	Depending on the application, the main risks are: - Too many changes in the standard product due to specific project requirements - Onboard integration longer than expected - Development of interface with existing Traffic Management System - The standard ERTMS product includes too many functionalities not used by the owner

1. BANEDANMARK SIGNALLING PROGRAMME

Facing significant problems of reliability and punctuality due to near-obsolete signaling equipment on both their main line network (Fjernbane) and on the Copenhagen heavy rail network (S-bane), Banedanmark (the Danish rail infrastructure manager) concluded on a business case for a total replacement country-wide of their signaling systems.

Therefore in 2009 the Danish Parliament authorized funding for the 3.2 billion Euros “Signalling Programme” [1].

Figure 3: Danish railway infrastructure [1]

This programme is managed by Banedanmark, in close collaboration with the different train operating companies (TOCs) in charge of train service on the different parts of the network.

In this case the choice of the new signaling system was different for the two types of network:

1. The main line passenger and freight services (Fjernbane) will be fitted with ERTMS level 2
2. The Copenhagen heavy rail transit system (S-bane) will be fitted with CBTC

The decision to choose two different systems was mainly due because the S-bane is a standalone system and does not share service with the main lines. The S-bane also operates today like a heavy rail metro (albeit in manual mode versus the future ATO mode).

The decision to install ERTMS level 2 on the main lines was mainly driven by the willingness of Banedanmark of adopting a proven and standard technical solution for the new signaling and with interoperability capabilities in order to ensure smooth cross-border service in the future with its neighboring countries, Sweden and Germany.

In both cases the choice of ERTMs level 2 and CBTC has been done with the goal of significantly reducing the maintenance costs for the life of the system by:

- Removing all existing track-circuits and wayside signals
- Specifying a minimal fallback system using axle counters and fixed signs markers
- Contracting the maintenance to the signaling suppliers for 25 years (for the infrastructure)

With this strategy, Banedanmark will be able to save at least 25% annually in maintenance cost for the infrastructure equipment.

But beyond the life cycle cost saving, these new signaling systems will bring additional benefits to the end-users due to the increased level of automation (especially in the case of CBTC for the s-bane). Banedanmark is also considering very seriously to implement Automatic Train Operation to the main line rolling stock fleet in order to increase capacity on some parts of the network and to better manage energy consumption.

The sections hereafter present an overview of the future potential benefits brought by the programme.

Main benefits for the S-bane network (CBTC)

The S-bane is a 180 Km heavy rail mass transit system network serving Copenhagen and its suburbs.

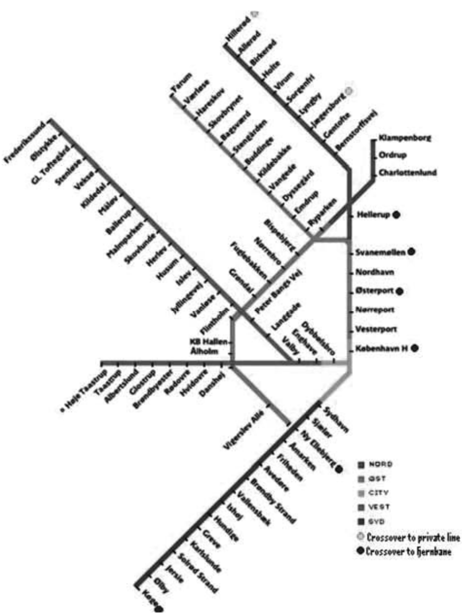

Figure 4: Copenhagen S-bane network

In addition of the life cycle cost saving due to the elimination of most of the wayside equipment (track-circuits and wayside signals) and better managed maintenance using advanced and centralized diagnostic tools, the new signaling system for the S-bane will offer several other benefits to the operator and ultimately to the passengers. Among them are:

- Improvement of punctuality
- Potential capacity increase

- Improvement of train regulation

Improvement of the punctuality on the S-bane

Improvement of punctuality is the prime business objective for Banedanmark.

Banedanmark currently uses the Train Path Punctuality (TPP) as measure for punctuality, which can be described as the punctuality delivered by the Customer given a required traffic volume.

The Train Path Punctuality improvements are expected to be achieved by a significant improvement of the overall dependability of the signalling systems, i.e. fewer failures that impact punctuality.

The top level business requirements for dependability (which have been the basis for implementing the Signalling Programme) have been defined as: 0.8 % (points) improvement in S-bane Train Path Punctuality

This requirement has been apportioned to the various S-bane systems by Banedanmark as a maximum allowable Irregularity Percentage (IP) for each system. For the new signaling system the monthly IP target has been set to 0.45 points. This translates into a target of a maximum 4.5 train delays out of 1000 timetabled departures. A delay is defined as a train being late 150 seconds or more compared to the timetable arrival time or being cancelled.

The supplier of the new system will have an incentive to achieve this target monthly as he will be responsible for the maintenance contract and its payment will be based on the measured performance.

Because the new system (CBTC) is built around software and is data driven, this will also allow to build a much more efficient and functional interface with the existing punctuality monitoring tool used by Banedanmark.

Increased capacity due to automatic train operation (ATO) and moving block design

Even though the existing train control system, which is based on fixed block and speed codes, is designed to provide a 2 min headway in the central section of the network, it is already optimized to the limit of the system and cannot offer any improvement. Moreover in case of perturbation there is no “room” available for absorbing delays.

The new CBTC system will allow the trains to operate in automatic driving mode (ATO). This will enable decreasing the headway between trains of a few seconds as it eliminates the train driver reaction.

At some terminal locations the system will support automatic turnback operation in order to gain an additional few minutes.

In addition the train safe separation will be ensured by virtual moving blocks which will allow to shorten further the headway between trains, as their occupancy will be based on the actual position of the trains calculated onboard (positive train detection).

These design concepts will permit a throughput of 40 trains per hour in the central section of the network and 30 trains per hour in the branches, compared to respectively (actual) 30 trains per hour in the central section and between 6 and 12 in the branches.

Improved train regulation functionalities

One of the key features of the new CBTC system to be implemented on the S-bane is the implementation a state-of-the-art Traffic Management System (TMS or ATS). The TMS which is fully integrated within the CBTC system and in particular with the ATO functions will ensure that the traffic can be automatically regulated. One critical functionalities of the TMS is the "Decision Support Tool" which will ensure that each perturbation of the traffic can be mitigated in an efficient manner by proposing to the service manager and signalmen different scenarios to recover delays. This tool will have some pre-programmed scenarios to address typical perturbation and can also be updated with additional specific situations by the users.

The TMS will provide powerful software driven tools to improve the traffic regulation as well as centralized maintenance and failure condition information to the maintenance team.

The punctuality and the capacity of the network will both be improved thanks also to the TMS.

Because the TMS is a data-driven system it is also able to interface with external systems critical for the passengers travelling experience, such as the Passenger Information System and the CCTV cameras security system installed in stations.

The Passenger Information System will be able to provide more accurate information about train arrivals and delays. It will also be able to transmit additional information such as the reason the delay…etc.

Main benefits for the Fjernbane network (ERTMS Level 2)

The main benefits that will be realized on the main lines network will be the improvement of the punctuality and the life cycle cost saving also due to the significant reduction of wayside equipment (all signals and track-circuits will be removed as for the s-bane).

The Fjernbane will also be fitted with a new Traffic Management System to better regulate the different services.

Beyond these benefits, Banedanmark is looking at improving further the capacity on some lines by introducing automatic train operation (ATO) as an overlay to ERTMS. The ATO will also allow to reduce the traction power consumption.

ATO for ERTMS is a relatively new concept that has not be implemented yet in revenue service. However several infrastructure managers are in the process of implementing it or considering to implement it (ex: Network Rail for the Thameslink core section).

Banedanmark has developed a business case for implementing ATO on the main lines and is currently taking a staged approach for the design and implementation phase. At each stage of the process, risk and costs are evaluated and a GO/NO-GO decision is taken to move to the next stage.

The first stage, which was a feasibility study, was completed in August 2012. The scope of this study was to investigate in a qualitative manner the business case for ATO. The study has developed the following:

- Cost model
- Benefits model
- Concept solution

The current stage is the "Design Development". Its main objectives are to:

- Detail the technical solution (preliminary design and interface specifications)
- Refine business case
- Improve benefit and risk assessment.

The benefits have been assessed for the three main stakeholders of the signaling programme: the Customers (passengers), the Train Operators and Banedanmark (Infrastructure Manager).

Then main benefits are:

- Customers: travel time saving
- Train Operators: energy (cost) savings and lower capital and operating costs (due to less vehicles and staff needed for a given traffic)
- Infrastructure Manager: lower operating cost, more potential revenue if additional capacity sold (passenger and freight traffic).

Capacity increase:

The capacity gains due to ATO are expected to be in the Copenhagen area.

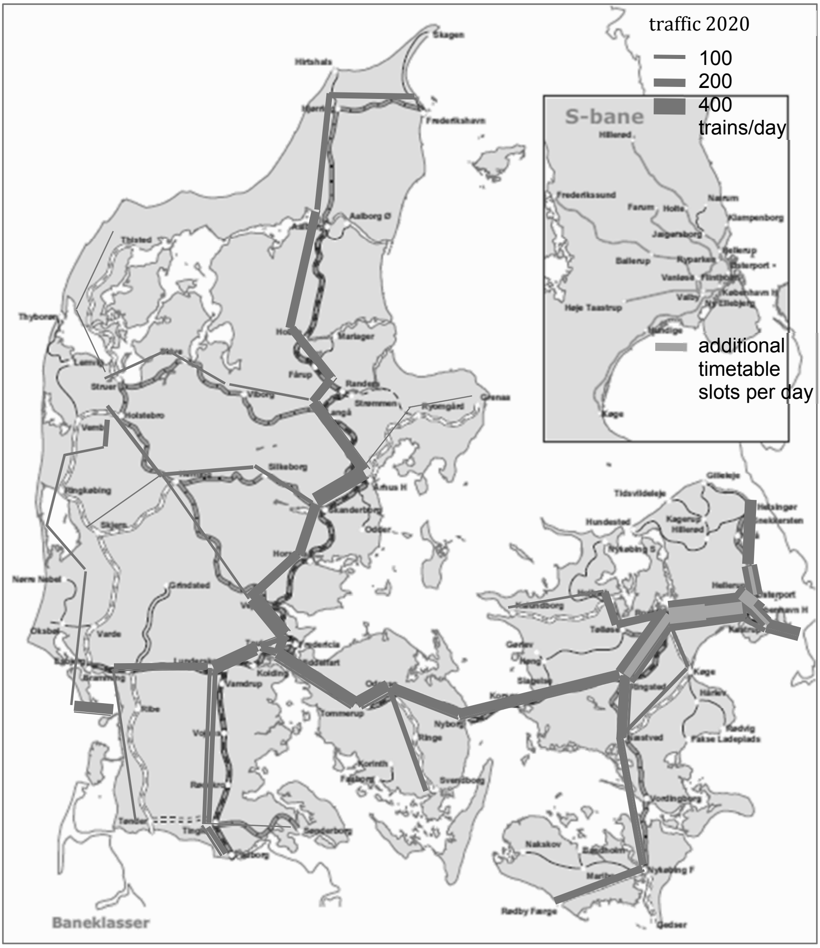

Figure 5: Capacity gains on the national network [2]

The additional timetable slots per day are shown below.

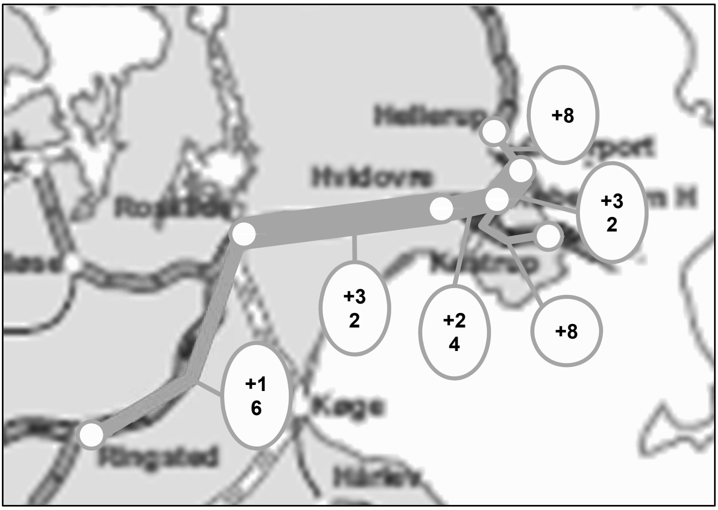

Figure 6: Additional timetable slots in the Copenhagen area [2]

Energy Saving

As part of the current benefit model refinement, Banedanmark has also concluded that ATO will bring significant cost saving regarding energy consumption.

DSB, the main Train Operating Company for passenger traffic in Denmark has implemented a few years ago a train driver advisory system called "Green Speed". This system provides the train drivers some indications for speed regulation in order to optimize the braking and traction curves to save energy. Even compared to this system, ATO will bring another 16% in average in energy consumption saving [2].

The main ATO features enabling this additional saving are:

- Using the Traffic Management System, ATO can ensure to avoid conflicts and unnecessary stopping.
- Optimising the speed profile (Train Operation).
- A better utilization of the spare time built in the timetables. Usually 90% of the trains arrive too early in stations. ATO can enforce the travel times, to ensure that trains arrive on time and can regulate intermediate timing point while focusing on optimizing braking/traction curves.

Next steps: implementation

If Banedanmark decides to go forward, the next steps in the ATO implementation for the mainline are:

1. Capability realisation

The number of trains and routes will be selected during this phase. There are between 600 and 700 candidate trains.

During this phase the supplier will perform the software and hardware engineering as well as verifying the different ATO solutions available. In particular the supplier will ensure that the engineering is aligned with the TEN-T (UNISIG, Users group) standardisation process.

It is important also to ensure that the pre-conditions to enter the rollout phase are well defined in order to not jeopardize the current ERTMS onboard programme.

The different stakeholders will be constantly engaged to verify their commitments, especially the train operating companies. The business case will also be updated.

2. Application Design and Implementation

ATO will be implemented to the selected trains and routes. The supplier will perform the installation design for each First of Class (FoC), as well as the test and commissioning. Safety approvals and training together with Banedanmark and the train operating companies.

3. CONCLUSION

Benefits driven approach

Banedanmark is implementing the largest re-signalling programme in the world. Because of its huge size, Banedanmark has chosen to focus on the benefits to be delivered and to follow a risk management approach at each phase of the programme (feasibility, tendering, contracting) instead of designing specific technical solutions. Now with all the contracts being signed with the signaling suppliers, Banedanmark is constantly reviewing the different business cases to ensure that the expected benefits can be achieved and that all the risks are controlled.

State-of-the art CBTC system for the S-bane

It was decided during the programme phase - prior to enter into the procurement phase - that the existing S-bane signaling system will be replaced by a state-of-the art CBTC system. The new system will be as much as possible “off-the-shelf” (to minimize the risk associated to new developments) and will ensure that the expected benefits can be achieved: improved punctuality and potential capacity increase. The high level of automation and redundancy built in the CBTC system will allow to achieve these benefits.

Future additional benefits are also being explored with potentially converting the S-bane network to full driverless operation.

Future trends for the main lines: ERTMS using ATO

There is a clear trend in the railway industry to converge some of the main line services into a “metro-like” type of operations using ATO. Because ATO was never specified as part of the Technical Standard for Interoperability (TSI), there is a potential risk of specific development that needs to be carefully managed by the infrastructure manager / train operating companies.

Banedanmark’s objectives are to improve punctuality and capacity on their national network. The rollout of the standard ERTMS Level 2 system will achieve these objectives. Beyond these objectives, Banedanmark' vision is to further unlock capacity and enable some other benefits such as energy saving by rolling out ATO on the entire national network or on selected lines, depending on the refined business case. This vision, if implemented, will drag the entire signaling industry to an all new level of developing converging systems for mainline applications and metro type applications.

NOMENCLATURE

ATO: Automatic Train Operation

ATS: Automatic Train Supervision

FoC: First of Class (typical train for a given fleet)

LCC: Life Cycle Cost

CBTC: Communication Based Train Control

ERTMS: European Rail Traffic Management System

TMS: Traffic Management System

TSI: Technical Standard for Interoperability

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HOV/HOT Lane Vehicle Characteristics: A Case Study on Atlanta's I-85 HOV-TO-HOT Corridor

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Abstract

The conversion of high-occupancy vehicle (HOV) lanes to high-occupancy toll (HOT) lanes was implemented in metro Atlanta as a pilot project and is under consideration for more widespread adoption throughout the metro region. Further conversion of HOV lanes to HOT lanes is a major policy decision that depends upon the likely impacts, including lane performance and equity impacts of the new HOT lane. This research effort collects revealed preference data in the form of observed traffic counts, vehicle license plate data, and vehicle occupancy data to study the impacts of the conversion. Building upon methodologies developed in Spring 2011, researchers are matching field-collected license plate data with vehicle occupancy data. Vehicle occupancy data from the first four quarters of data collection prior to the conversion are used to create the distribution of occupancy on the HOV and general purpose lanes, and then the transit and license plate data are analyzed. Preliminary post-conversion data are also included in the analysis. A conclusions section suggests possible impacts of the findings on policy decisions as Georgia considers expanding the HOT network.

Introduction

Managed lanes remain a popular topic in transportation planning due to continued increases in congestion, ongoing concerns regarding vehicle emissions, and decreasing funds and available space for highway expansion. High-occupancy vehicle (HOV) lanes have been in existence since 1969, and the introduction of high-occupancy toll (HOT) lanes in the 1990s has added another alternative for highway management (Fuhs and Obenberger 2002). The performance of such managed lane facilities is evaluated in a number of ways, including the assessment of effective capacity, travel times, service reliability, vehicle occupancy (person throughput), carpool violation rates, and safety. At the disaggregate level, many studies have also sought to identify reasons why people choose to carpool or ride express buses on these facilities, usually as a function of various socio-demographic variables and travel time. The study of vehicle occupancy and the characteristics of the vehicles that use managed lanes can provide useful information for emissions modeling and studying the effects of transportation policy on travel behavior.

Metropolitan Atlanta is already home to a limited high-occupancy vehicle (HOV) lane system, and the most congested HOV-equipped corridor was converted to a high-occupancy toll (HOT) lane in October 2011. The purpose of this study is to create a profile of vehicle characteristics of carpoolers on the HOV lane and the adjacent general purpose lane for before and after the conversion of HOV to HOT, and compare the two profiles. The research effort will also analyze the characteristics of the occupancy distribution for both lanes prior to the conversion. Creating a pre-conversion profile of the lane users and the occupancy by vehicle will assist policy makers in evaluating the impact of the lanes on different user groups.

Literature Review

The HOV lane concept was first introduced in 1969 in New Jersey when a bus lane borrowed a lane from the off-peak direction (Fuhs and Obenberger 2002). The temporary bus lane was so successful that the construction plan was altered to include two permanent HOV lanes (Fuhs and Obenberger 2002). As of 2001, the most popular type of HOV lane was the concurrent-flow lane. Approximately 48% of all HOV lanes are buffered (separated by a physical barrier) concurrent lanes and 28% are non-buffered concurrent lanes (Fuhs and Obenberger 2002). Many HOV lanes initially were used for buses and 3+ carpools, but over time the vehicle occupancy requirements have changed to mainly 2+ (FHWA). By 2000, because such lanes typically ran under capacity, over 80% of HOV lanes in the United States operated on a 2+ basis, and about half of HOV lanes operated on a 24-hour basis. The 3+ facilities operate in areas with heavy congestion such as San Francisco and Houston (Fuhs and Obenberger 2002).

HOV Lane Performance

Carpooling generally implies that multiple people riding in one vehicle will replace single drivers operating in multiple vehicles, but this is not always the case. When carpools are composed of related family members (known as “fampools”) the vehicle does not displace other vehicles on the roadway as the carpool would form without any form of incentive (Burris, Ungemah et al. 2009). Nevertheless, carpooling and carpool lanes have the potential to reduce the number of vehicles using a freeway corridor. Past research has suggested that many HOV lanes do not function properly, in that the lanes operate below capacity or the lanes become congested like their general purpose lane counterparts (Guin, Hunter et al. 2008). Commuters often complain when a carpool lane is moving freely that the lane is underutilized given the low density of vehicles passing by the general purpose lanes (Hart 2011). On the other hand, in corridors where carpool demand exceeds capacity and the HOV lanes become congested, commuters do not benefit from going to the extra effort to form a carpool.

In Atlanta, the I-85 HOV lane became congested on a regular basis, but the congestion onset was delayed by a short period compared to the general purpose lanes (Guin, Hunter et al. 2008). That previous study found that the congestion may not have been due only to high demand for use of the HOV lane, but may also have been associated with an unwillingness of drivers on the HOV lane to have a larger speed differential with vehicles on the adjacent (non-barrier separated) general purpose lanes (Guin, Hunter et al. 2008). A study in California found that HOV lanes are 20% under capacity in comparison with the general purpose lanes and one highlighted reason is the presence of "snails", or slow vehicles in the HOV lane which hold up the flow of all cars in the lane (Kwon and Varaiya 2007). Congestion levels can also result from the prevalence of single-occupant vehicle (SOV) violators in the lane, which is estimated to be 13% in metro Atlanta (Zuyeva 2009). The net result is that the carpool lane does not exhibit predictable travel times due to the onset of recurring congestion with severity that varies significantly day-to-day.

HOV lanes generally encourage carpooling. However, a shift of demand into an HOT lane could result from people switching out of carpools or transit and into SOVs. Hence, it is possible that HOT lanes could potentially reduce demand for transit ridership along the route. The potential of a mode shift from transit users to single-occupant vehicles exists when an HOV lane is converted to a HOT lane, but a survey-based study in Houston concluded that transit passengers shifting to SOV vehicles would only impact the occupancy of the lane by 1-2% (Chum and Burris 2008). The study also examined ridership information from the years immediately preceding and following HOT conversion at other facilities (I-394 in Minneapolis and I-25 in Denver). Neither city experienced a decrease in transit ridership on the HOT corridor, and Minneapolis actually recorded significant increases in ridership (Chum and Burris 2008). One of the cited reason that transit ridership on I-394 did not decrease is that transit buses also benefit from the more reliable trip times and that buses are better able to access the lanes due to dedicated entrance ramps (University_of_Minnesota 2006).

HOV Exemptions

The underutilization of HOV lanes has resulted in several policy changes, including conversion to HOT lanes and allowing alternative fuel vehicles (AFVs) access to the HOV lane. Alternative fuel vehicles include cars powered solely by electricity, hydrogen, natural gas, biofuel, propane, fuel cell, or other miscellaneous alternative fuels (GSA 2011). Multiple states, including California, Florida, Arizona, New Jersey, New York, Utah, and Virginia have piloted or implemented programs that expand this policy to allow single-occupant hybrid electric vehicles such as a Toyota Prius or Honda Insight to use HOV lanes (Gallagher and Muehlegger 2011).

Beginning in 2000, Virginia was one of the first states to allow single-occupant hybrids access to HOV lanes (Gallagher and Muehlegger 2011). Hybrid HOV access was found to have a positive correlation with hybrid sales in Virginia as hybrid sales increased 92% after the implementation of the new policy (Gallagher and Muehlegger 2011). In 2004, Virginia commissioned a report on the status and future of the hybrid HOV exemption, and the study authors concluded that either the occupancy levels for hybrid vehicle should be increased or that an increase in the issuance fee for the "clean special fuel" plate from $10 to $500 should be implemented so that the extra funds can be used for further enforcement and maintenance of the HOV facilities (Morrison and Counts 2005). Rising congestion levels in the peak periods resulted in a change in the hybrid exemption policy to involve specific rules for each HOV facility. For example, only hybrid vehicles purchased prior to July 1, 2006 can use the I-95/395 HOV lanes during peak periods with fewer than three occupants and these vehicles have clean fuel license plates to facilitate enforcement (VDOT 2011).

Carpooling Activity

License plate data can provide revealed preference information about users of a transportation corridor. Revealed preference data are preferable to stated preference data which may derive from employee-based surveys. Travel surveys can also be used to obtain carpooling information; however, the data may be limited. A survey was conducted in the Puget Sound region for the purpose of tracking commuters who switch between carpooling and single-occupant vehicles and vice versa. The study was limited by the small sample size (very few people switched from SOV to carpooling within the survey period) and the only significant variable that could be identified as motivating a switch was when respondents moved to a zone with a higher residential density (Wang and Chen 2011). Another problem is the under-representation of certain groups in surveys. In one survey that attempted to estimate mode choice for travelers on a new HOT facility in Texas, the responses did not represent a true sample of the socioeconomic characteristics of people in the area, so paper-based surveys were issued in low-income areas. The number of low-income and minority responses was still too low to be reliable, so the researchers undertook a weighting process using replicate weights to make the low-income and minority responses equal to population proportions (the end result of the survey found that the percentage of HOV2s and HOV3+ vehicles would only decrease slightly after the conversion to HOT lanes) (Burris, Ungemah et al. 2009).

Previous studies have set out to correlate socio-demographic variables with carpooling rates to guide policy decisions, but in many cases only weak correlations are discovered. Factors such as lower income, lower automobile ownership rates, and multiple worker households appear to link back to carpooling (Teal 1987). A more recent study examined the factors further using a survey data and nested logistic regression models and found that vehicle occupancy, household income, trip purpose, and age are predictors of HOT lane use (Li 2001). Specifically, there was a positive correlation between household income and HOT lane use (high income households were 18% more likely to use the lane). Each additional passenger in a vehicle increases the likelihood of using the HOT lane by 92%, and travelers who make home-based trips were three times as likely to use the HOT lanes (Li 2001).

The use of the vehicle characteristics to create a profile of carpool vehicles versus general purpose lane vehicles may help to identify variables that influence carpooling, such as vehicle body type (e.g. larger vehicles) or household vehicle ownership. Such variables may also be correlated with underlying reasons for carpooling and may be more reliable than survey or surrogate data. If public agencies can better understand the type of vehicle that tends to be used for carpools, they may be able to use this information to target these audiences with new policies. This research effort used vehicle license plate data to assess these correlations.

Methodology

The current HOV-to-HOT Corridor Performance Monitoring project is collecting vehicle occupancy and license plate data. The new methods developed in 2010 are based upon a 2007 study that collected over 120,000 license plates using spotting scopes and voice recorders. The earlier method successfully captured 20-30% of passing vehicle plates (Nelson, Zuyeva et al. 2010). Given the large sample size, capture rates using the visual/voice recorder method were sufficient for analysis, but recording all of license plates later became possible in 2010 with the increasing quality and lower costs of high definition digital video cameras (see Figure 1).

Figure 1: HD Camera Set-up and View

License plate videos are now collected quarterly at five different sites along the northeast I-85 corridor. At each site, data are collected during the morning (7:00-9:00am) and afternoon (4:30-6:30pm) peak period for at least three days per week. High definition cameras are set-up on overpasses to record traffic in the peak direction only; southbound in the morning and northbound in the afternoon . The videos are then processed by student assistants using a purpose-built, custom software program. Students input the plate information, state, vehicle classification, and any comments using graphical user interface. The vehicle classification (LDV, SUV, or HDV) is only entered for missed license plates and out-of-state plates. The classification for Georgia plates is obtained from the registration database information.

Occupancy Data
Vehicle occupancy data are collected concurrently with the license plate video data (even though the data are collected concurrently, the plate and occupancy data streams are not paired). A recent thesis, “Methodology For Collecting Vehicle Occupancy Data On Multi-Lane Interstate Highways: A GA 400 Case Study,” describes in detail the occupancy data collection methods used in this project and how they were developed (D'Ambrosio 2011). The occupancy data are collected using the roadside observation method, with data collectors positioned in the gore area between the highway and the entrance/exit ramp. Data collectors record occupancy values using electronic keypads, netbooks, and custom software (refer to Figure 2). One data collector is assigned per lane, and the lanes are numbered beginning with the HOV lane as Lane 0 and counting up to the rightmost lane (Lane 4 or Lane 5 depending on the total number of lanes). Each vehicle is assigned a classification of either light duty vehicle (LDV), sport utility vehicle (SUV), or heavy duty vehicle (HDV) in addition to the occupancy values. Seven occupancy values are available on the keypad (1, 1+, 2, 2+, 3, 3+, 4+). The “+” values are intended for use when data collectors can see some passengers but are unsure about the presence of additional passengers due to visual constraints such as tinted windows or high speeds.

Figure 2: Occupancy data collectors and electronic keypad

Express Bus Data
Bus data were collected September 13-17, 2010 and October 10-14, 2011 by Gwinnett County Transit bus operators (the HOT lanes opened October 1, 2011). Drivers record the bus departure time and then the arrival time at the end of the route. Drivers also record the traffic conditions, weather conditions, number of passengers, and if casual carpooling was observed at any stops (only in 2011). Bus occupancy is high and will impact ultimate occupancy results for corridor, so making adjustments to the data collected via the roadside collection method is important. Unfortunately, the occupancy data from the buses were not available at the time this publication was prepared sooccupancy values reported do not yet include the transit share.

Data Processing

License Plates
Each decoded license plate was assigned a unique key identifier, and Georgia license plates were matched to the motor vehicle registration database. Duplicate plates (i.e. multiple sightings of the same vehicle) were left in the data set, and these duplicates accounted for about 25% of the total number of plates. Approximately 80% of the processed plates yielded a match in the motor vehicle registration database. Each vehicle is assigned to its applicable census block group. Processed results contain vehicle-specific data that exclude any personally identifiable information such as name or physical address.

These records included 194 different vehicle makes and 2,417 different vehicle models. All trailers were excluded from the make and model recoding process due to the diverse models and makes and the fact that the trailer details are not representative of the vehicle that is hauling the trailer. The vehicle make list includes many uncommon manufacturers such as Hino, Daewoo, and Datsun, but the list did not contain any duplicates. In contrast, the vehicle model list included many different iterations of the same model type. The full list of 2,317 models was reviewed and duplicate fields were combined while still including model variations that reflected different engine types (i.e. an “Accord DX” was changed to simply “Accord “while a “Jetta TDI” remained separate from “Jetta”). Only 858 vehicle models remained after the recoding process.

Occupancy
Occupancy data files for all sessions other than Fall 2010 contain the name of the student assistant who collected the data. Over the four quarters of data collection, over 65 different students collected vehicle occupancy field data. Each individual’s occupancy distributions can be separated according to session, site, day of the week, time period, and lane. The occupancy distributions are compared across several of these variables to assess the potential accuracy of the data. Several anomalies emerged in the distribution of occupancy values which motivated further analysis of the data. Occupancy distributions are expected to vary slightly, but due to the large sample size, the distributions across different sessions should be comparable. The data from several individual data collectors were identified as biased and all data collected by these employees were removed from the dataset. The overall impact of this data removal on the total number of observations in the study was not significant. The identified biases were addressed through additional training for all data collectors.

Data Analysis

License Plates
Data collected in Spring 2011 are used for the pre-conversion profile and data collected in Fall 2011 are used for the HOT lane profile. The HOT lanes opened on October 1, 2011, so the presented results are preliminary and are a much smaller

sample size than the spring data. Chi-square tests were performed to compare the independence of different variables for Lane 0 (the managed lane) and Lane 1 (the adjacent general purpose lane) for the HOV lane and the HOT lane (complete results of the tests are available in the author's recent thesis (Smith 2011)). A 95% confidence level was used in the analysis. Due to the large sample size, almost all tests were significant, although for most comparisons the differences in magnitude of the values being tested were very small.

Vehicle Ownership

The vehicle registration database assigns one of three ownership values for each vehicle: commercial, government, and private. Approximately 7-9% of vehicles are commercial, less than 1% government, and 90% private (the percentages are similar for both the pre- and post-conversion data). In spring 2011, the percentage of commercial vehicles in the HOV lane was 11% while the percentage in the general purpose lane was only 8%. After the HOT lanes opened, the overall percentage of commercial vehicles dropped to approximately 7%, with the majority of the decrease in the HOT lane. This drop in the percentage of commercial vehicles in the HOT lane was contrary to expectation, as businesses were expected to take advantage of the opportunity to pay for more reliable trip times. This may change over time as businesses come to realize the potential time savings benefits.

Although the total number and percentage of government vehicles on the road was small (only 460 government vehicles were observed in the spring and 92 in the fall), the percentage of government vehicle using the carpool lane was nearly seven times higher than in the adjacent general purpose lane. The percentage of government vehicles in the HOT was expected to increase, since overall volumes are lower and new transit routes were added to the corridor in summer 2011, but the percentage actually decreased slightly from 1.7% to 1.4% (the chi-square test results show significance at the 95% confidence level).

Vehicle Classification

Vehicle classifications were included as body type in the registration database, and the twenty-five different body types were re-coded to the three vehicle classifications used in occupancy data collection. The actual count of heavy duty vehicles in the HOV lane was twice the expected count, and the opposite was observed in the adjacent general purpose lane (Lane 1) where the actual count of HDVs was only 40% of the expected count. This trend continued to a greater extreme in the HOT lane data, with HDVs accounting for 1.8% of all vehicles in the lane. Even though HDV vehicles were more prevalent in the HOV and HOT lanes, they are still one or less percent (0.8% and 1.0%) of all vehicles (compared to 0.2% on Lane 1). On the HOV lane, SUVs accounted for nearly 60% of vehicles in the carpool lane but less than 50% of vehicles in Lane 1. The HOT lane did not show this difference, with very similar percentages of SUVs on the HOT lane and Lane 1 (45.6% and 46.1%).

Fuel Type

Alternative fuel vehicles are slowly gaining popularity in the United States, and this data set provided an excellent opportunity to take closer look at the prevalence of these vehicles in the I-85 commute fleet. The strict federal definition of alternative fuel vehicle, which is also used by the State of Georgia, does not include gasoline hybrids like the popular Toyota Prius (GSA 2011). Alternative fuel vehicles under the federal definition qualify for Georgia AFV plates, which allow drivers to use the carpool lane.

Five different fuel types are recorded in the registration database: diesel, flex fuel, gasoline, hybrid, and natural gas. Diesel vehicles accounted for 4.5% of vehicles in the HOV lane but only 1.8% of vehicles in Lane 1, and the gap in percentages narrowed after the HOT conversion with 2.6% of vehicles in the HOT lane and 1.7% in Lane 1. The high proportion of diesel vehicles in the HOV lane correlates back to the high number of commercial and heavy duty vehicles in the lane. Flexfuel vehicles are eligible for official "AFV" license plates in Georgia, but the actual count of these vehicles in the HOV and HOT lanes was only slightly more than expected (3.4% and 4.2%). Not all flexfuel vehicles have the AFV license plate, and only 93 total vehicles with the official Georgia "AFV" license plate were observed in the spring data set and 21 in the fall dataset. On the HOV lane, of the 72 AFV vehicles that returned records from the registration database, there were only 22 unique vehicles (most vehicles were observed on more than one day). The HOT lane had 13 unique vehicles despite the much smaller sample size.

Hybrid vehicles are much more prevalent than official AFV vehicles, with 544 records from the registration database. A previous study used uncommon variables such as Sierra Club membership levels to examine the relationship between environmentalism and propensity to carpool (the study did find a positive correlation) (Gallagher and Muehlegger 2011). Based on this previous work, researchers hypothesized that hybrid vehicle owners would be more likely to carpool. While the results of the first chi-square test for fuel type as well as the test results with gasoline excluded were significant, there was no practical difference between the percentage of hybrid vehicles on the HOV lane and Lane 1. The percentage of hybrid vehicles actually increased on the HOT lane (from 0.9% to 1.5%) and overall percentage of hybrids in both lanes increased as well (from 0.9% to 1.2%).

In-State vs. Out-of-State Vehicles

Out-of-state vehicles observed in this data collection effort may just be passing through the region. However, since the collection only took places during peak commuting periods it is likely that many of these vehicles are garaged in Georgia but registered in another state (this could also apply to vehicles registered in distant Georgia counties). Previous research in the Atlanta area found that approximately 67% of vehicles have the registration database address as the point of origin (Granell 2002). The percentage of out-of-state vehicles in the HOV lane is slightly higher than in the adjacent general purpose lane, and also about 20% higher than the expected count from the chi-square test. The percentage of the out-of-state vehicles in the HOT lane drops to just 1.6% while the overall percentage of the vehicles on both lanes remains very similar (4.2% compared to 4.4% in the spring data). Vehicles must register for a PeachPass to use the HOT lane, so out-of-state vehicles that use the lane infrequently are less likely to own a pass than local vehicles.

Occupancy

The processed occupancy data for all four quarters were analyzed to examine the impact of factors such as site, day, and time on the occupancy distributions. For each observation, vehicle occupancy, vehicle classification, student data collector name, and a time stamp are recorded.

Overall HOV vs. General Purpose Occupancy

The preliminary HOT lane data indicates that the average occupancy value of the lane has dropped (from around 2 persons per vehicle to 1.39 persons per vehicle) but is still higher than the general purpose lanes (about 1.15 persons per vehicle). This occupancy value is expected to increase over time as more carpools utilize the HOT lane. The average occupancy values of each lane for each data collection session are illustrated in Table 1. Note also, that these occupancy values do not yet include the contribution from the express buses operating on the corridor as occupancy data were not yet available. Given the preliminary reported ridership increase of 4% noted by the agency after opening, the authors expect the average occupancy data to be higher than reported in the table below.

Table 1: Average Occupancy by Lane

Session	Lane 1	Lane 2	Lane 3	Lane 4	Lane 5	HOV/HOT Lane
Fall 2010	1.07	1.09	1.15	1.15	1.13	1.96
Winter 2011	1.08	1.08	1.11	1.14	1.13	2.0
Spring 2011	1.06	1.06	1.09	1.13	1.20	2.03
Summer 2011	1.05	1.11	1.06	1.12	1.11	2.01
Fall 2011	1.16	1.15	1.15	1.14	1.15	1.39

Uncertain values changed to numerical values for this calculation ("1+" → "1.5").

Occupancy of Buses and Vanpools

The occupancy values collected using the roadside method do not allow an occupancy value of more than 4+ to be recorded. This limitation introduces a bias in the occupancy values when considering buses. Using ridership data from the two regional transit agencies, GRTA Xpress buses and Gwinnett County Transit buses, the average bus occupancy in spring 2011 was 28 persons per bus for routes that utilize the study corridor. Exact counts for May 2011 for each site were obtained to maximize the accuracy of the average occupancy per bus. A total of 73 buses were observed and had consistent occupancy records (this translates to approximately eight buses per hour). Once the estimated bus occupancy values of "4+" are replaced with the actual occupancy value of 26, the average occupancy for the dataset would increase from approximately 2.0 persons per vehicle to 2.3 persons per vehicle. Vanpools could also have an effect on the overall occupancy rate, but there are no available data on occupancy or frequency of these vehicles.

Buses are expected to make up a larger percentage of vehicles on the HOT lanes than the HOV lanes due to the expanded transit service included in the project funding, so the "4+" values may produce a much lower average occupancy than in reality. The analysis of the preliminary HOT lane is not complete and therefore the new percentage of vehicles on the HOT that are buses is not yet known. Using the data from the transit agency, the average passenger count for buses on the corridor was about 28 persons per bus for both fall 2010 and fall 2011 (pre- and post-conversion). Post-conversion occupancy data are not yet available for these new routes.

Conclusion

This research effort reported a profile of HOV and HOT lane users on the HOV-to-HOT conversion corridor on I-85 in metro Atlanta using license plate data, vehicle occupancy data, and transit data. This profile is then compared to a preliminary profile of HOT lane users after the lane conversion in Fall 2011. The study compared the vehicle characteristics of the HOV lane and the adjacent general purpose lane in I-85 before and after the HOT conversion. The post-conversion HOT profile did not yet reflect an increase in commercial vehicles as expected. There was a decrease in out-of-state vehicles, which was expected since registration is required to access the Express lane (i.e. fewer tourists or business travelers in the lane). Vehicle characteristics and census block group demographics alone cannot predict carpooling behavior, but the fleet composition information may help policy makers target potential carpoolers in the future. The information also indicates levels of participation in programs such as the AFV-exempt group, especially if policy makers consider expanding the exemption to hybrid vehicles. Future research will include using the vehicle characteristics for emissions modeling, creating targeted travel surveys to learn more about trip purposes and origins/destinations, and a comparison with the vehicle characteristics and profile post-HOT conversion.

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Design of Access Facilities and Modal Integration for Major Transit Projects in Developing Countries

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ABSTRACT

Success of major transit projects depends on the design of access facilities to stations and terminals and integration of all transit modes. In developed countries, the major access modes to fixed guideway systems depend on the location of stations (suburban, inner city, and downtown). At suburban stations, primary access mode is the automobile; bus serves as secondary. At inner-city stations, bus is the primary access mode and if the station is surrounded by dense development, walk also serves as a significant access mode. At downtown stations, walk is the primary mode followed by bus circulator system.

Many major cities in developing countries are now seriously contemplating building major fixed guideway facilities such as subways, elevated rail and monorail, and bus rapid transit. However, while these capital intensive projects are planned, very little attention is paid to the access modes, such as walk, bicycle, motorcycle/scooter, auto/cycle rickshaws, which serve a very significant percentage (almost 65%) of the total person trips in the cities. In addition, bus operations should coordinate with the rapid transit system to avoid duplication of services. In developing countries integrated sidewalks, bicycle paths and parking, parking facilities for motorcycles/scooters, drop off facilities for auto/cycle rickshaws, and bus circulation facilities are more important than auto parking to the success of proposed rapid transit facilities.

This paper will highlight the importance of the popular modes in developing countries and their integration with proposed capital-intensive transit projects in achieving an efficient and functioning system for the public from opening day as well as promoting the use of more sustainable modes of transportation to access the new facilities.

INTRODUCTION

The largest population increases in the world are occurring in developing countries. The population increase in developing countries is creating mega cities as seen in Table 1. As cities in developing countries becoming bigger and bigger, the mobility of people and goods in these cities becomes more and more crucial to the survival of the people and the nations' economies.

Table 1. World Cities

	1950	1994	2015
>10 million People	**1**	**14**	**26**
In Developed Countries	1	3	6
In Developing Countries	0	11	20

Source: United Nations

Urban transportation in developed countries is more or less limited to automobile and bus. In large cities, fixed guideway systems such as underground and/or elevated rapid transit systems exist. In developing countries, urban transportation is very complex with many travel modes such as walk, bicycles, motorcycles/scooters, auto and cycle rickshaws, buses and jitneys, taxis, cars, vans and trucks. All these modes are highly relevant to different income groups in developing countries and integrating them for efficient mobility of people and goods is essential.

ACCESS FACILITIES TO RAIL RAPID TRANSIT SYSTEMS IN DEVELOPING COUNTRIES

Large cities in developing countries have built and/or are contemplating implementation of fixed guideway systems such as underground and elevated rail rapid transit systems (popularly known as Metros) and Bus Rapid Transit (BRT) systems. Success of these systems depends on the design of access facilities to stations and terminals and integration of all travel modes to provide seamless travel. Access modes to the fixed guideway systems depend on location of stations (suburban, inner city, and downtown). At suburban stations, in order to cover long distances to stations, access modes are usually motorized modes, such as the automobile, motorcycle, auto rickshaws, and bus. At inner-city stations, bus is the primary access mode and if the station is surrounded by dense development, walk, bicycle, auto/cycle rickshaws, and motorcycles also serve as significant access modes. At downtown stations, walk is the primary mode followed by bus circulator systems, if any. However, land use around the stations make the station areas as trip generation or/and trip attraction zones.

Each station in the Metro systems of developing nations has to be properly designed and the relevant access modes in the catchment area of the station have to be properly integrated. Ridership on Metro systems depends on the facilities provided and efficient integration of the modes.

As a case study for developing countries, India and Delhi Metro are analyzed to establish the importance of access facilities to Metro systems in developing countries.

ACCESS MODES TO METROS IN DEVELOPING COUNTRIES – CASE STUDY IN INDIA

Table 2 shows the modal split of person trips made in India by city size.

Table 2. Modal Split in Indian Cities by City Size, 1994 (in percentages)

City Size	**Travel Modes**							
Population (in million)	Walk	Mass transport	Intermediate public transport, IPT Fast	Slow	Car	Two-wheeler	Bi-cycle	Total
0.10 – 0.25	37.1	16.4	10.4	20.1	3.3	24.1	25.7	Do not add
0.25 – 0.50	37.8	20.6	8.9	17.2	2.6	29.8	20.9	to 100 because
0.50 – 1.0	30.7	25.4	8.2	12.0	9.5	29.1	15.9	percentages are
1.0 – 2.0	29.6	30.6	6.4	8.1	3.3	39.6	12.1	averages
2.0 – 5.0	28.7	42.3	4.9	3.0	5.0	28.9	15.9	under each city
5.0 +	28.4	62.8	3.3	3.7	6.1	14.8	9.4	size

Source: Traffic and Transportation Policies and Strategies in Urban Areas in India. Final Report, Ministry of Urban Development, Government of India, New Delhi, March 1998.

Large cities are expected to have large bus systems or Metros supplemented by bus systems. Per Table 2, as the size of city increases, transit share is increasing. Although the data in Table 2 is almost 20 years old, the modal distribution, even under increasing auto ownership during the past 20 years, has not changed significantly, as seen in Table 3. At present, transit usage level in Indian cities appears to be reasonable because of captive riders; however, the transit services are not at satisfactory levels in terms of comfort and convenience. With degradation of transit services and lack of satisfactory access facilities, people are likely to shift to private modes (car and especially to motor cycles). With new Metros in large cities, transit services will improve but their usage depends on the quality of access facilities to stations. Bus feeder systems are quite popular. Potential increase in ridership on Metros will be from shifting of motorcycle users and car users to Metros; the level of this shift to Metros depends on availability of facilities for parking motorcycles and cars at stations. This kind of shift not only increases Metro ridership but also reduces congestion on city streets.

Table 3 shows the modal split in City of Chennai (formerly called Madras), the fourth largest city in India, with a commuter rail system, which is not as ubiquitous as typical Metro. Access facilities to stations to this commuter rail system are not satisfactory. So, the share of ridership by train is minimal (only 5 percent).

Table 3. Modal Split in Chennai in 2004 (in percentages)

Population in millions in 2001	Travel Modes						
	Walk	Mass transport (Bus + Train)	Intermediate public transport, IPT Fast/ Slow	Car and Other	Motor Cycle/ Scooter	Bicycle	Total
4.34	28	29 + 5	2 / -	4 + 1	18	13	100

Source: Draft Master Plan II, Chennai Metropolitan Development Authority (CMDA), 2007

As seen from Tables 2 and 3, irrespective of size of the city, about 30 percent of total person trips are made by walk and a significant percent of trips (about 15 percent) are made by bicycle. So, access facilities to Metro stations by walk, bicycle and auto/cycle rickshaws are also very important in developing countries.

NEW DELHI METRO IN INDIA

A new Metro system, called Delhi Mass Rapid Transit (DMRT) System, is operating in New Delhi, the capital city of India. Because it is a capital city, it is not a typical city. The city has higher automobile ownership and usage than other large cities in India.

Figure 1. Delhi Metro, India
(Source: Wikipedia, the free encyclopedia)

As of August 27, 2011, Phases I and II are complete, with the network comprising of six lines with 142 metro stations and a total length of 189.7 km (117.9 mi) as shown in Table 4.

Table 4. Phases I and II of Delhi Metro Rail Corporation

	First operational	Last Extension	Stations	Length (km)	Terminals		Rolling stock
Red Line	December 24, 2002	June 4, 2008	21	25.15	Dilshad Garden	Rithala	23 trains
Yellow Line	December 20, 2004	September 3, 2010	34	44.65	Jahangirpuri	HUDA City Centre	45 trains
Blue Line	December 31, 2005	October 30, 2010	44	49.93	Noida City Centre	Dwarka Sector 21	59 trains
	January 7, 2010	July 14, 2011	8	8.75	Yamuna Bank	Vaishali	
Green Line	April 3, 2010	—	15	18.46	Inderlok	Mundka	15 trains
	August 27, 2011	—	2	3.32	Kirti Nagar	Ashok Park Main	
Violet Line	October 3, 2010	January 14, 2011	15	20.04	Central Secretariat	Badarpur	29 trains
Airport Express	February 23, 2011	—	6	22.70	New Delhi	Dwarka Sector 21	8 trains

Source: DMRT Website

PASSENGER ACCESS SURVEY AT THREE DELHI METRO STATIONS

A brief and limited survey was conducted for this paper to understand modal split in access modes to three stations on Red Line (Nethaji Subhash Place, Pitampura, and Rohini West stations). Brief descriptions of areas surrounding the three stations are given below.

Netaji Subhash Place Metro Station

It is located on the north-west of Delhi, near Wazirpur bus depot and Pitampura TV Tower. The Metro Station is named after the Netaji Subhash Place, a commercial and shopping centre. Max Hospital, Hotel City Park and some schools are located near the station.

Pitampura Metro Station

This station serves Pitampura, an affluent residential area of North Delhi district of Delhi, India. It is a planned neighbourhood developed by the Delhi Development Authority (DDA) in the 1980s. Pitampura TV Tower was built in 1988. Dilli Haat Pitampura, situated near the TV tower, is an upscale residential, commercial and retail centre. The area is encompassed between Outer and Inner Ring Roads, NH-1 and Rohtak Road.

Rohini West Metro Station

This station serves West portion of Rohini, a 30-year-old well-developed residential suburban city in North West Delhi. There is another Metro station by name Rohini East serving the eastern portion of Rohini. It was the first mega suburban city project of Delhi Development Authority (DDA) under the urban extension of Delhi, started in 1980s to provide housing for all income groups. It is one of the 12 zones of the Municipal Corporation of Delhi. Rohini is a peaceful residential area not yet saturated with people and businesses. It consists of many parks and gardens. Rohini has some of the best residential developments in different sectors. Table 5 shows feeder bus routes serving the three station areas.

Table 5. Feeder Bus Routes at the Three Stations Surveyed

Station	Feeder Bus Route	Places served by the bus route	Route Length in KM
Netaji Subash Palace (elevated)	Route 1 Ajadpur PRS (ML-11)	Guru Govind Singh Institute, Tikona Park, Gopal Mandir, City Park Hotel, Pitampura Blk, G & JU, KU, NU, QU, EU, DU, CU, BU, AU Blocks, Green Apptt., Pitampura, Gian Shakti Mandir, Jhulelal Mandir, Prabhu Dayal School.	5
	Route 2 Bhagwan Mahaveer Hospital (ML-12)	Bhagvan Mahavir Hospital, Kesav Mahavidalaya . Road No. 43, Shri Guru Harkrishan Marg, Rani Bagh, Mahindra Park, Rajdhani Enclave,Maharana Pratap Enclave, Raj Nagar, Samrat Enclave, Shakurpur, Britannia Chowk, Netaji Subhash Place MetroStation.	6
Pitampura	Pitampura Metro Station (ML-15)	Durga Mandir, Rohini Sector-7&8 Xing, Sector-7A Part-I, Naharpur Village, Ayodhya Chowk, Vikram Chowk, Rithala Mor, Rajiv Gandhi Cancer Hospital, Rithala Metro Station, Rohini Sec-11, Ambedkar Chowk, Rohini Sec-16, Sec-15, Sardar Colony, Pocket-B2, Manav Chowk, Sachadeva School, Sec-13, Veer Appt.,Neelgiri Appt.,Auther's Appt.,Rohini Sec-9,Jaya Appt., Rohini Sec-7, Rohini 7& 8 X-ing, Madhuban Chowk.	13
Rohini West	Route 1 Rama Vihar (ML-17)	Rohini Sec-5, Avantika, Budh Vihar, Puth Kalan, Rohini Sec-21, Maharaja Aggarsen Institute, Begampur, Jain Nagar	9
	Route 2 Lakhi Ram Park (ML-18)	Rohini Sec-22 Pkt-17, Sec-21, Sec-20, Sultanpuri Bus Terminal, Mangolpuri (Y-Block, K-Block, J-Block, I-Block, H-Block, D-Block), Kam Dhenu School, Avantika, Rohini Sec-1, Sec-4, Sec-5, Rajiv Gandhi Cancer Hos.	9

(Source: DMRC Website)

The station catchment areas are multi-use comprising of residential, commercial, and institutional with both trip generation and attraction zonal characteristics. Land use surrounding the stations can be understood from the places served by the feeder bus routes of the stations.

Survey of passengers entering stations was conducted during 7:30 pm to 8:30 pm. A simple question was asked regarding how the passengers arrived to the station. Table 6 shows the modal split of access modes at these three stations.

Table 6: Shares of Access Modes to Stations Surveyed
(Passengers entering stations during 7:30 pm to 8:30 pm)

ITEM		Station Name		
		Netaji Subash Place	**Pitampura**	**Rohini West**
Available Parking Spaces	Cars	100	60	None
	Motor Cycles	300	200	
	Bicycles	Spaces are encroached by vendors		
Date of Survey		Feb 15, 2012	Feb 16, 2012	Feb 17, 2012
Sample Size		352	129	163
Modal Shares (in Percent)				
Non-motorized	Walk	32	19	18
	Bicycle	--	--	--
Public Transit	Bus	12	7	18
Intermediate Public Transit (Rickshaws)	Auto Rickshaw	30	35	31
	Cycle Rickshaw	10	15	25
Private Vehicle	Car	5	9	2
	Motor Cycle/ Scooter	11	15	6
Total		100	100	100

The limited passenger survey clearly highlighted the importance of modes usually found in developing countries, such as autorickshaws and cycle rickshaws, which combined amount to 40 to 56 percent of the total station accessing trips. Walk served as access to the station close to shopping center (Nethaji Subash Place) with about 30 percent share while walk shares to stations serving residential areas (Pitampura and Rohini) are about 20 percent. This concludes that walk, auto and cycle rickshaws, and motorcycles have a major role in accessing Metros in developing countries and station area designs should properly incorporate these access modes. Although there is a significant bicycle ridership in the city, bikes are not being used to access the stations because the bike parking spaces are taken away by vendors. Providing accessible bike racks free from encroachments by vendors may create good bike use as station access mode.

Hypothetical Station area Design for Metros in Developing Countries

Figure 2 is a hypothetical station area plan to show circulation patterns for all available access modes to Metro stations in developing countries.

The hypothetical design includes circulation of all access modes that are available in developing countries. Station is assumed to be over (elevated) or under (subway) a major arterial road and with access facilities to Metro station on both sides of the street. The access modes are:

- Pedestrians: Footpaths connecting Arterial Street and station
- Bicycles: Bicycle parking facilities
- Bus: Bus/Metro transfer facilities
- Automobile: Park-and-Ride and Kiss-and- Ride facilities
- Motorcycles/Scooters: Park-and-Ride and Kiss-and-Ride facilities
- Auto and cycle rickshaws: Access and Parking facilities

Depending on constraints at specific station locations, appropriate changes have to be made in the circulation patterns.

CONCLUSIONS

The capital-intensive major transit projects, such as Metros and BRTs in developing countries have to place special emphasis on travel modes that are common and widely used by the public in developing countries. Designing station areas with proper access facilities by these common modes will enhance ridership of these projects as well as ease congestion on urban streets. The statistics and travel patterns in developing countries clearly exhibit that although as the automobile ownership is increasing, percent of person trips made by automobile is very low; the major modes of travel are walk, cycle, bus, motor cycles/scooters, and auto/cycle rickshaws. Station area designs have to give proper consideration to provide convenient, comfortable, and safe access facilities by these modes. Too much emphasis on automobile access to stations as in developed countries will not meet the mission and satisfy objectives of the Metros in developing countries.

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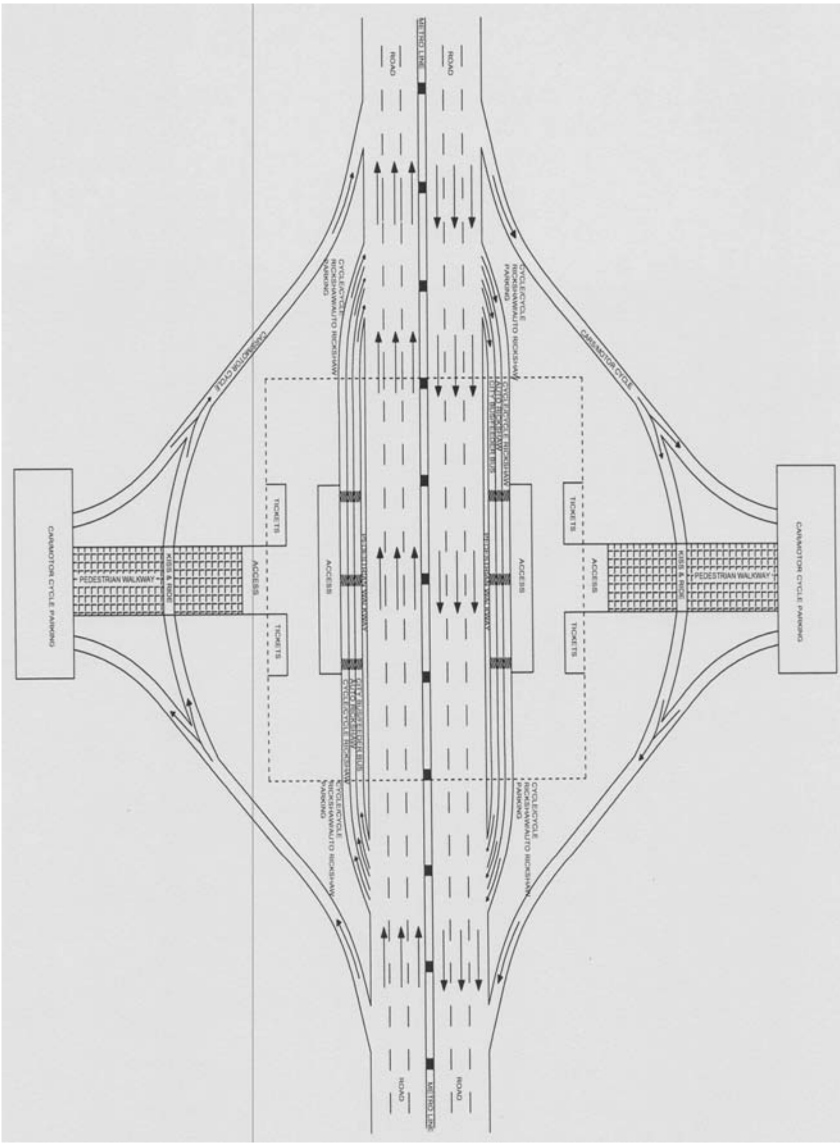

Figure 2. Hypothetical Station Area Plan for Metro Station in a Developing Country

Security Considerations in Transportation Infrastructure Development

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ABSTRACT

Topic: Considering Security in the Project Development Process

Importance of Topic:

- Provide specific recommendations for inclusion of security considerations into the project development process that would have immediate utility.
- Facilitate planning/programming efforts and result in an additional screening tool that can be used to evaluate potential transportation projects and more accurately assess the benefits and costs of those alternatives.
- Serve as instructional material for training decision-makers.
- Establish methodology for comparing alternatives.
- Assist with justifying management decisions for altering programming, budgeting, and staffing assignments that differ from previous norms.
- Encourage technical/research needs in transportation security planning.
- Increased efficiency/effectiveness of decision-making by educating decision-makers on potential fatal flaws.
- Use in both man-made and natural disasters.

Relevance to Audience: There are clear guidelines that motivate/facilitate the transportation decision-making process. However, these guidelines lack provisions for security considerations in the development and decision-making processes. The purpose of this paper would be to include and move considerations for security needs into the project development arena.

Information Sources: Sources would include personal experience as a practicing planner and engineer, current planning practices, current security practices, and research.

Present position and background: I am currently the Chief Operating Officer for a private consulting firm that specializes in long-term transportation asset management and engineering services. I have more than 20 years of experience in planning, design, operations, construction, and maintenance of transportation infrastructure.

Security Considerations in Transportation Infrastructure Development

Much of the interest in the transportation security planning processes has emerged in large part due to post-September 11th terrorism fears and there is a marked interest in emergency response efforts throughout all types of transportation planning mechanisms. However, highly visible flaws in security have been exposed to the general public and to experts in the field, which have created considerable challenges in their efforts to overcome these gaps in knowledge and information (Dornan and Maier 2005). In metropolitan areas, where these processes are highly visible and prominent, it is especially critical to develop and implement security strategies that will accommodate the specific needs and calm the fears of residents that utilize various forms of transportation (Dornan and Maier 2005).

Transportation infrastructure development has become a complex issue. We routinely consider a wide range of issues including engineering, financial viability, environmental impacts, safety, economic development and stability, transportation options, route efficiency and effectiveness, public opinion, and system interoperability. These challenges grow in both number and size as issues related to security have increased in importance. Terrorist threats have increased in scope and incidence over the past quarter-century, and consequently, transportation systems continue to require additional security measures to be prepared for such events (Jenkins 1997). With the continuous acts and threats of violence and terrorism, infrastructure has become increasingly vulnerable. It is increasingly difficult to modify systems, without interrupting the flow, progress, financial viability, and integrity of the systems. The level of security that is provided by our transportation infrastructure is perhaps the key measurement that planners must consider.

The transportation infrastructure development process takes on many forms, often as a result of government guidelines and processes. The associated decision-making processes often lack adequate provisions for security, resulting in an immediate need for security considerations to permeate through and saturate the infrastructure project development process. The inclusion of enhanced security considerations requires tremendous commitments of time and resources to develop implementation models. It is difficult to develop new strategies and processes for security improvements without financial resources or political will. Strategic measures must be taken that will enable planners to develop processes that are designed to fill the voids of current processes, emphasizing security-enhancing measures that are lacking in many modern systems. These measures should include a review of current planning practices; modal factors; system factors; financial factors; public interaction; and the role of technology.

Current Planning Practices: There are historically assumptions that can be made during the planning process that have proven to be fairly accurate. For example, safety has routinely been considered in the project development process for several years. It is common to review crash data, accident reports, and other safety related data in an effort to better design and construct a safer facility. However, security considerations have been absent. It is important to distinguish between safety and security and to realize that they should be evaluated and managed with different strategies in mind, as noted: “Safety initiatives often have no bearing on the security of transportation facilities or services, and security initiatives may not impact the safety of transportation facilities or services” (Dornan and Maier, 2005). It is important to not group these concepts together because their primary objectives and strategies should remain unique and distinct from one another throughout all planning processes.

Current planning practices allow control of key transportation decisions at various levels. Some decisions are made at the federal level whereas others are made at the state or local level. For example, in the United States, the Department of Transportation controls the flow of federal transportation dollars but the local Metropolitan Planning Organizations or County Commissions assign project priorities. As a result, the obligation fluctuates to the point where the responsibility for security considerations is not adequately defined. There should be a clear definition of who is responsible for addressing security issues during transportation planning. There should also be clarification of who, outside of the traditional organizations involved in planning, needs to evaluate those issues. Considering the impact of terrorism in modern society, field experts and government officials must be effectively prepared to manage such attacks on their systems without creating additional panic or harm whenever possible (Jenkins 1997). In developing an effective security strategy for transportation systems, it is critical to reexamine current priorities and involved parties to determine if any new stakeholders or key players must be considered in the planning process (Dornan and Maier 2005). A greater level of oversight and guidance from national response teams is absolutely critical in developing an effective response strategy, as these teams are much more knowledgeable of the requirements and cost of enhanced security measures in the desired location (Dornan and Maier 2005). Furthermore, these teams often provide manpower and other resources that are not readily available at the local level due to limited financial resources or other limiting constraints (Dornan and Maier 2005). Regardless of the type of system under consideration, it is anticipated that extensive knowledge and resources from federal agencies is required in order to develop effective long-range security strategies (Dornan and Maier 2005).

Land use decisions are another traditional area of planning that needs to better consider security. Many questions arise about what effect security considerations have upon topics such as zoning and access management. The current planning processes consider land use when establishing system routes and alignments. When perceived through a security planning framework, that process of alternatives evaluation will need to be modified. If additional security events occur in highly populated areas, some shifts in migration patterns may occur as a result. This may become more important as governments begin to look at transportation corridor preservation. If security becomes one of the main criteria in evaluating and establishing these corridors, land use will be affected.

Modal Factors: In determining the best possible course of action regarding security for a given transportation system, it is necessary to identify and understand the level of progress that has already been made towards modal integration. There are a number of key issues to consider in developing transportation strategies that incorporate mode specific security needs into their processes. It is advantageous for field experts to begin to manage these challenges with an all-inclusive examination of current modal processes, many of which may appear outdated and ill-equipped to accommodate emerging security needs; however, there is a marked lack of understanding between what is perceived as critical and how to promote such issues in modern systems. With this in mind, it is not surprising that transportation planners continue to struggle in their efforts to identify the specific problems of each system and to develop strategies to overcome these problems without lengthy or severe interruptions to current processes, which might cause even further delays in maintaining adequate systems on a long-term basis. Nonetheless, these challenges must be faced directly and without fear, as transportation continues to evolve and to require the expertise and support of a wide body of groups in order to thrive, since individuals depend upon transportation in order to conduct their lives normally and without serious disturbance to their routines.

Modal attractiveness, both existing and influenced, is an important factor for transportation planners. Being able to determine the modal split is a fundamental consideration in the transportation and traffic modeling systems. It seems logical that if a planning study does not consider transportation alternative to be viable due to concerns associated with the security of that mode then the attractiveness of that mode would be artificially altered as a result of that finding. This would most likely be a short term effect due to the resilience of modal patrons and the dependency of those users on the systems. However, it could prove annoying and difficult to properly analyze revenue potential of a particular mode and to deal with other long-term planning issues such as infrastructure needs. There should be sensitivity to the effects of identifying modes, routes or infrastructure that are more vulnerable to security issues. Polzin (2002) discusses the issue of modal attractiveness in light of September 11th. He discusses the impacts that September 11th had on the airline industry and the subsequent shift in mode choice. He also discusses the possible discrepancies that could occur as a result of mode based security funding differentials. These differentials, or publicly perceived differentials, could greatly influence modal attractiveness.

System Factors: System factors such as performance and interdependency must also be considered when incorporating security into the planning process. Polzin (2002) discusses the issue of system performance as the “most obvious area of impact to transportation.” He proposes that security concerns can impact the cost to user, speed, accessibility, reliability, safety/security, convenience and connectivity. The consideration of security in the planning process will mean a redefining of traditional performance criteria and formulas. Currently, most systems are evaluated independently when dealing with planning, design, funding, operation, and maintenance considerations. This is partially driven by the fact that systems are funded through different means that are directly related to the type of system. For example, federal roadway resurfacing dollars are not normally used to fund a new bus station along a roadway. The current transportation planning process struggles to consider different modes or systems collectively or it simply considers them independently. This is not a desirable situation from a security planning perspective or from an overall efficiency standpoint. The planning processes should take into consideration the interdependency of these systems in evaluating security issues and in resources allocations. It is strongly suggested that all transportation planning processes must account for enhanced security measures and objectives whenever possible. However, these goals are very difficult to achieve and maintain without a specific strategy, which involves a variety of public agencies and private groups, as well as general public awareness of the possible threats to the security of these systems. Examples of these security vulnerabilities include entrance and exit points, where many users are likely to be found waiting for their chosen mode of transportation to arrive and depart (Nelson 1999). Furthermore, fuel used for buses, electrical switches, train or rail tracks, and computer systems must be continuously evaluated for any unexpected changes or threats (Nelson 1999). These steps are necessary in the development of any routine transportation planning process, and officials must not take these concerns for granted, since it is possible that terrorists may identify these vulnerabilities and take dangerous action if it is known that there are weaknesses in a given system (Nelson 1999). If at all possible, the development of emergency response plans that include the evaluation of possible tampering of systems and vulnerable areas is particularly advantageous in developing an effective security planning process (Nelson 1999). Much of the lack of preparedness for terrorist threats to transportation systems has been in faulty designs and the lack of knowledge regarding threats when these systems were created; therefore, it is often required that systems must undergo modifications in order to update equipment, exit and entrance locations, and computer systems in order to better recognize threats that may occur, as well as to better prepare users for the possibilities that might exist, allowing them to increase their awareness of such events (Nelson 1999). It is also expected that as transportation planning initiatives continue to emerge throughout the United States, there must be considerable measures in place that will accommodate the many users of public transit systems, including buses, railways, and subways. However, prior to the development of any revised guidelines for emergency preparedness in transportation systems, the following assessments must be conducted and evaluated:

- A general risk assessment must be performed in order to evaluate the potential threats against a system in a given location;
- The likelihood of serious hazards stemming from acts of terrorism must also be considered; and

- There must be a comprehensive strategy in place to manage any perceived risks or hazards that might occur as a result of a terrorist attack or threat (Boyd and Sullivan 2000).

There is a critical need in transportation planning processes to evaluate and consider the long-term outcomes of terrorist acts or threats, since these may incite fear in passengers, leading to a reduction in use of such systems over time. If passengers are assured that their time spent in the transit system is as secure as possible; there is a greater likelihood that these circumstances will be managed more effectively and without serious consequences. Nonetheless, passengers must also be assured that their time spent on the public transit system will be secure, and this requires an extensive effort from all responsible agencies to ensure passengers that all measures are being taken to facilitate smooth travel time.

Financial Factors: Transportation planning strategies serve as a substantial portion of the United States gross economic product, with approximately $1 trillion (2006) in spending on an annual basis. This figure represents a relatively large portion of federal spending for programs, and since transportation infiltrates almost every aspect of daily living, this funding must be expended wisely and without waste in order to preserve the credibility of these processes. With the increased interest in promoting security within these processes, it is not surprising that continuous assessments of transportation planning must take place in order to utilize such allocations as best as possible so that residents are protected and supported by their own tax dollar. However, transportation planning has long been weak in many of these areas, as there have been considerable flaws in how security measures are provided to the public, their flexibility, and their overall long-term sustainability, considering the financial resources that are available for use. There is considerable evidence to suggest that transportation planning strategies require a complex evaluation of current processes and routine needs assessments in order to promote change and progress regarding security measures. For example, some of the key required steps include financial forecasting of projected costs regarding operations and new program implementation; the utilization of existing land versus new land requirements; the feasibility of growth opportunities in existing regions in order to accommodate new users; the ability to utilize new and existing capital resources to maximize transportation opportunities; and identify areas of weakness and the potential for widespread improvements that will best influence transportation system users without serious interruptions to daily activities. The development of modified transportation planning processes requires extensive funding from a wide variety of sponsors, including federal, state and local agencies. Federal funding is especially critical in developing new security strategies for transportation, and there is a general rule that as spending is incurred upon approval of a given project, costs will be reimbursed by the federal government for the work that is performed in a given location (The Metropolitan Transportation Planning Process 2005). Each year, Congress is responsible for allocating a specific amount of funding for specific projects deemed necessary for the general operations of the U.S. Department of Transportation, with specific spending guidelines for many programs (The Metropolitan Transportation Planning Process 2005). Much of this funding is required to maintain existing operations within a given location; however, some project-specific funding is usually available for facilitating new programs that may include measures for security and other related issues (The Metropolitan Transportation Planning Process 2005). It is expected that as these needs arise, funding will be requested by states and local governments for specific projects, and that transportation experts, upon notification of funding, will implement their chosen strategies in order to promote greater effectiveness in the transportation planning process (The Metropolitan Transportation Planning Process 2005). Funding for transportation projects can be controlled, in both amount and allocation, by many factors. Unfortunately, security is not one of them. Safety is a very prominent factor in that it can generate funds in a very short time frame. Changes to existing systems will not go unchallenged because the addition of a single factor will cause competition for limited funds with other projects. The most critical funding criteria are identified as ridership level, population, identified vulnerabilities, and criticality of assets. Funds should also use risk-based criteria for fund distribution. Two key funding and accountability challenges will be (1) paying for increased transportation security and (2) ensuring that these costs are controlled. The funding estimates for security projects do not come close to matching the project demand. Costs associated with security planning can consist of both direct and indirect costs. Direct costs can include design, construction, maintenance, and operation of improvements for both retrofit and new projects. Indirect costs can include right-of-way value impacts, cost of additional labor, tourism impacts, investment attractiveness, and delays associated with changing priorities. Currently, it is common to consider these costs when making transportation decisions. These considerations usually take the form of a Benefit/Cost analyses. The current practices do not assign quantifiable benefits to a particular security consideration. Therefore, it is not possible to adequately incorporate those considerations into the analyses.

The strategic development of transportation planning processes that involve security require that there must be substantial knowledge of the risks involved with maintaining these elements, as they are often very difficult to achieve without adequate financial resources. However, it is just as important to understand that security efforts are limited by the ability to secure funding for such projects at the local, state and federal levels, and that if these resources are scarce or are lacking altogether, little if any progress is anticipated in ensuring that transportation users feel more secure in their travels (Dornan and Maier 2005). It is important to recognize the varying degrees of risk that are involved in threats to transportation systems, and this often requires an extensive examination of risk levels. Upon review and evaluation of the appropriate levels of risk involved in a given transit system, it is critical that the corresponding emergency preparedness strategy is also established in order to provide the best possible short- and long-term outcomes (Boyd and Sullivan 2000). Risk considerations are often mitigated through improving design practices. This is somewhat of a self-policing process which involves modifications to current practices once a risk threshold has been crossed. In the planning process, risk must be estimated for at least two reasons: (1) to determine what additional costs may be associated with a project due to increased risk that requires additional considerations, or (2) to determine if a potential project is considered feasible due to properly considering security risks. It may be necessary and beneficial to adapt and transfer current practices in other industries to the transportation planning arena. This would most likely greatly reduce the “learning curve” and allow more rapid application of these assessment methods to transportation planning by taking advantage of the lessons learned in other areas.

It is most important to recognize that in promoting new security measures for implementation in modern transportation systems, any number of possible scenarios or opportunities for security mishaps can occur, such as with natural disasters or with threats of terrorism. Transportation planning processes have long been ill-equipped to handle these types of threats, which have exposed serious defects in how these systems account for emergencies, regardless of their source (Dornan and Maier 2005). These flaws could potentially lead to fatal errors if they occur, and therefore, it is critical that transportation planning strategists are well-prepared to manage these challenges on a widespread and long-term basis (Dornan and Maier 2005). System redundancy can provide alternative transportation modes and routes when available. A traditional utility of redundancy is that of alternatives associated with primary system failure as a result of events, such as crashes, or lack of capacity. The value of redundancy is clear when observed from the user’s perspective. However, the value becomes less apparent or is mitigated when dealing with funding these redundant systems. Honea (2000) ventured into the topic of the planning of excess capacity. Excess capacity was recognized as a necessity for the national defense. Certain types of industries, like the rail industry, struggle to redeploy or add capacity due to the fixed nature of their infrastructure. This occurs even in the presence of reliable demand forecasts that justify the need for additional capacity. Other modes, like containers, deal with a trade imbalance of high import, low export of containers. Therefore, ships are already making trips with empty containers. Excess capacity for redundancy or capacity considerations is extremely difficult and costly. Morgan (2000) believes that the existing surface transportation system has a tremendous amount of redundancy built in as evidenced by the system’s rapid recovery after natural disasters.

Public Interaction: One of the major initiatives over the past 20 years has been to enhance the transparency of the transportation planning process and to provide and encourage the public to be more involved in this process. Many of the existing practices require a public involvement phase to successfully continue the project development phase. When security considerations are factored into the planning and decision-making processes, public participation can be problematic because the full transparency of the process cannot be maintained. These processes will lose transparency and the public may feel deprived of their access to data and therefore be less willing to support a decision without knowing all of the factors that were considered. Many transportation planning studies involve data that is considered the best available. The availability limit is imposed by both the cost of collecting additional data as compared to the anticipated value of the information, and/or the time constraints associated with the project development process. Planners need guidance on how to properly consider transportation security when the information is not the best available or is simply unavailable because of security concerns. Clear guidelines should be developed to assist agencies with the proper discovery and dissemination of potentially secure information. These guidelines should consider various classifications of infrastructure projects and the demographics associated with each. For example, a light rail project in an urban environment would involve additional guidelines not necessarily considered in a rural roadway project. Guidelines should also include resources, such as agency contacts, to assist the agencies in the decision-making process.

Role Of Technology: In the modern world, technology infiltrates each and every aspect of our existence. In transportation planning, technology is utilized in many different areas, as there are specific needs that are best accommodated through technological means. It is not surprising that transportation systems have evolved in recent years in order to satisfy all desired data collection and analysis needs as well as timely operation of infrastructure. For example, Intelligent Transportation Systems (ITS) has evolved as a primary means of providing exemplary service to transportation users and it offers a greater level of understanding of the challenges of modern transportation systems, including but not limited to emergency response (Siwek and Associates, 1999). ITS's use and associated databases for driver's license processing hold great potential for preventing security events through detection of terrorists before they have the opportunity to impact the transportation infrastructure. However, the value of those technologies is less tangible when dealing with planning of the same infrastructure. The installation and operation of these technologies requires coordination and the cost and utility of these systems needs to be completely explored in the planning phase. This is not a new challenge. The integration of various technologies into transportation systems has always been a challenge for leaders and experts in the field, as existing frameworks have often been unequipped to manage these challenges without serious interruptions to service (Siwek and Associates, 1999). Nonetheless, there are considerable advantages to the implementation of these technologies, as they provide a greater level of efficiency, increased response times, and financial savings over the long term (Siwek and Associates, 1999). It is expected that with continuous improvement on strategies incorporating emerging technologies, these systems, in theory, will be prepared for security events, such as terrorist threats or attacks (Siwek and Associates 1999).

Other technological considerations must include the widespread dissemination of knowledge and information regarding these processes to elected leaders and other officials (Volpe Center, 2000). These initiatives are particularly important in facilitating the change that is necessary in providing the best possible measures for security and related support across all transportation systems, as they offer the appropriate personnel the knowledge and information that is required to make educated and well informed decisions that are likely to influence transportation systems in positive ways (Volpe Center, 2000). Furthermore, it should be noted that transportation planning without the implementation of technology initiatives will not be successful in providing effective options for end users, who serve as the most critical receivers of these systems (Volpe Center, 2000). With this in mind, it is critical to continue the education and advancement of technology initiatives for leaders, officials, experts, and even the end users (Volpe Center 2000).

The existing processes for infrastructure planning have evolved over many decades and through the tremendous efforts of administrators, engineers, planners, environmentalists and public involvement experts. Historically, changes to these processes have taken a slow path from an operations & maintenance retrofit to projection, planning and funding of future initiatives. In the case of properly considering security in the infrastructure development process, these processes must be expedited by the focused efforts of those same experts that developed the processes. Comprehensive steps must be taken to review every step of the current practices to ensure that security is properly considered in each of them. This will require the minor modification of some and possibly the wholesale replacement of others. We must be prepared to adopt these changes quickly in light of the potential effects of any delay.

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A Conceptual Physical Design of Bus Rapid Transit (BRT) in Dhaka

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ABSTRACT

Dhaka, the capital city of Bangladesh, is the largest and most industrialized city with 15 million people. Due to rapid unplanned development, versatile land use, rapid population growth, poor public transport system and increase of private car users, traffic problems is worsening day by day. The only mass transit is bus which is insufficient in terms of safety, capacity, comfort and convenience. Considering the worsening congestion it is high time to develop effective mass transit system such as Bus Rapid Transit (BRT) as a means for achieving sustainable urban transport in the city. In this paper an attempt has been made to propose a conceptual physical structure of BRT for the line3 which starts from Uttara and ends in Ramna covering around 18.5 km. The BRT stations and runways are designed in a way to satisfy the ever increasing public transport demand towards achieving a sustainable urban public transport system.

1. INTRODUCTION

The functional hub of administrative, commercial, industrial, educational and cultural activities of Bangladesh is Dhaka city, which has experienced phenomenal growth in terms of population and motorization in last three decades. It is often called Mega city, which indicates a large population agglomeration with more than 10 million (New Scientist Magazine, 2006). Currently the urban transportation of Dhaka mostly relies on road transport, where bus, car, three-wheeler, rickshaw etc. are coexistent. Eventually this creates serious traffic congestion in addition to health and safety hazard. With the present national economic growth, the urban population will gradually increase, at the same time the number of privately owned automobiles will also increase significantly. Therefore, the improvement of urban public transportation system of Dhaka city has become a pressing issue to improve its traffic situation as well as urban environment. Considering the current situation, the government of Bangladesh formulated a ‘Strategic Transport Plan’ (STP) with the World Bank in 2005. The STP prepared ‘Urban Transportation Policy’ for 20 years (2004-2024) and identified priority issues for improvement of mass transit system which include implementation of Bus Rapid Transit (BRT) in three arterial route of Dhaka city (Louis Berger Group and BCL, 2005).

Since the public transport system of Dhaka city is slow, inefficient, unreliable and complex, the transportation authority's need to introduce an improved and expanded system which will provide high quality with economically viable mass transit service. This leads to the most practicable and easily employable alternative, Bus Rapid Transit (BRT). BRT is a concept, increasingly implemented by cities looking for cost-effective and sustainable transit system. In this light, a conceptual physical structure for BRT line-3 has been proposed in this paper. The main objective of this paper is to propose a conceptual physical structure of BRT line3 which starts from Uttara and ends in Ramna covering around 18.5 km.

2. FEATURES OF BUS RAPID TRANSIT SYSTEM (BRT)

BRT is a system, better describe in terms of a set of elements which includes-runways, surface materials, stations, lane separation, vehicle and vehicle technology. Though it may not be possible to satisfy all the conditions, it is essential to address these components during planning and implementation for a successful and effective BRT system.

Runway is the most important element of BRT system as performance and effectiveness of other components to some extent depend on the characteristics and features of runway. However, choice of a particular type of runway from various available types, such as- mixed flow lanes with queue jumpers, on street bus lane, bus only street, elevated transitway, transitway following rail etc., mostly depends on the characteristics of transportation system of individual city. Other aspects of runway include- (a) guidance system which helps to ensure safe operation of vehicle with the help of guiding structure, mechanical or optical devices, (b) runway markings to highlight the distinction between general purpose lanes and BRT lanes. However, the existence of basic facilities in BRT runway can help to set stage for successful BRT operation.

Running ways should ensure rapid and reliable movement of buses with minimum traffic interference which render unique identity and assure efficient performance (Miller, 2009). In this regard, physical barrier is warranted in BRT runway. Landscaping, metal fencing, separating curbs etc. can be used to provide physical separation between BRT runway and non-BRT carriageway. However, provision should be available for emergency exit of buses that suddenly stop functioning. Again, other necessities like simple maintenance and enforcement, pedestrian safety etc. should be taken into consideration for designing lane separating structure (Arias et al., 2007).

Due to the fact that heavy loaded buses will move through the runway, provision of improved surface material demands special consideration. The appropriate runway surface material to sustain these heavy loads and specific design method for this purpose may vary from country to country. Unlike the overall runway, the deterioration of surface material in station and adjacent area is most critical as acceleration, deceleration of vehicle in this area increases the force on roadway surface and road bed. As a result, application of concrete instead of asphalt is more advised which provide higher longevity (Arias et al., 2007).

Station in a public transportation system is used as an interface between passenger and transit vehicle. Hence it is essential for these facilities to be convenient, comfortable, safe and easily accessible for passengers, supporting a strong identity of the system thereby enhancing the surrounding area context. Based on location, station can either be curb side or median type. Passenger access to the station depends upon the location of the station. Constructions of special infrastructures, such as: foot over bridge, underpass etc., are sometimes warranted for median type stations. In developing cities, may be 6000 passenger board or alight at a busy bus stop. Although it is suggested that station spacing should be in the range of 400-500 meter (APTA, 2010), it should also consider density of passenger demand, locations of large traffic generators, road geometries, availability of land, level of service required etc. The BRT station should portray a standard design giving due attention to supporting design issues such as passenger amenities, information, safety and security, climatic protection, pre-board fare collection etc. (CEPTU, 2005). These suggest that, one of the important role BRT station is to support an appealing, cohesive visual identity for a quality and safe transit service.

Vehicles used in BRT have strong influence on overall performance of the system, from ridership attraction to maintenance costs. To provide a distinct appearance and to create a unique identity, normally specialized vehicles are used for BRT system. Depending upon number of regulating factors, such as: travel demand, vehicle capacity, access facility, floor type, fuel and propulsion system, vehicle guidance etc., various type of vehicle is available for use which may include-standard bus, articulated bus, double decker bus etc.(CEPTU, 2005). Again, propulsion system choice for certain type of vehicle depends on performance indicators like top speed, engine, grade ability, transmission, and propeller shafts etc. Choice of BRT vehicle technology should also consider environment friendliness in terms of noise and air pollution as well as roadway surface deterioration. However, in most cases for developing cities, the choice of vehicle and vehicle technology is limited by governing legislation and economic evaluation of alternatives.

To put it briefly, every system has some basic components to build the skeleton of that system, without these components a system become some facilities without definite goal. The components mentioned above are the basic elements of a BRT system. Collective effort of these components with the provision of some important ancillary facilities, such as- fare collection system, intelligent transportation system etc., can establish a successful and physically sound BRT system.

3. CURRENT TRANSPORTATION SYSTEM OF DHAKA

Dhaka is one of the densely populated cities around the world. Like Dhaka, only seven cities experienced urban population growth higher than 2.4% between 1975-2005 (UN, 2006). In general, rapid growth, low incomes, and extreme inequality are among the fundamental reasons of transport problems in Dhaka, similar to every other megacity of developing countries (Pucher et al., 2005). In an ideal city, 25% of the surface area should be used for constructing roads and lanes, (Hossain, 2006) but Dhaka has only 8% (DCC, 2002). Moreover, like most of the developing cities, Dhaka's road network hierarchy is poorly defined, with very limited number of arterial and main roads. The prevailing situation is even worse when taken into account the fact that, this inadequate road space is shared by both motorized and non-motorized traffic (heterogeneous traffic mix) and vehicles with varying characteristics (e.g. three-wheelers, human haulers, pickups, vans etc.). Some striking features found from the survey conducted for 'Clean Air and Sustainable Environment' (CASE) project can be acknowledged as (Devcon, 2009):

- Buses comprise 9.7% of the vehicle mix that combines all vehicles and pedestrians;
- Rickshaws and vans comprise 28.4% of all vehicles;
- Auto-rickshaws (with 36.8%) and Cars/Light Vehicles (with 43%) comprise a substantial proportion of all motorized vehicles (2-stroke three wheelers);
- Whereas buses comprise a small proportion (9.7%) of the mix, bus passengers account for 77% of all people.

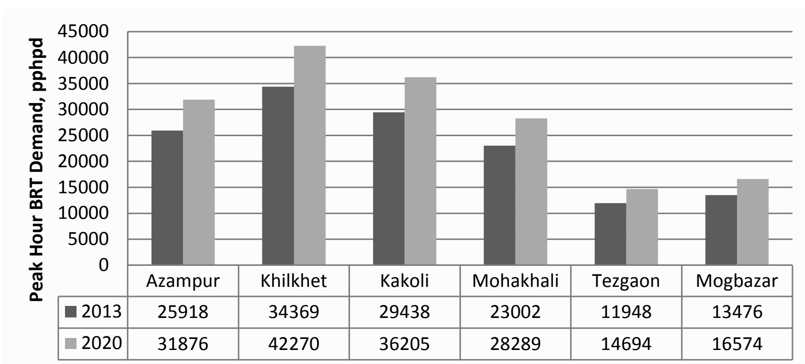
From Dhaka Urban Transport Network Development Study it was found that, the low income group is responsible for the major share of trips on foot (73%) while most of the rickshaw trips are made by the middle income group (59%) (DTCA, 2010). These two income groups are also main users of available transit services in Dhaka. The significance of walk, rickshaw and transit trips is obvious as they cater for 97% of the city dwellers. Unsurprisingly, very few of the lower income people (e.g. day laborers, garments workers etc.) can afford the fares on buses although they are quite low and most of their trips are short. Thus, they are forced to travel on foot, suffering ever-lower levels of mobility and accessibility.

The rapid urbanization process, poor transportation facilities and policies, varied traffic mix with over concentration of non-motorized vehicles, absence of dependable public transport system and inadequate traffic management practices have created a situation where cars and motorcycles are becoming increasingly necessity for the middle class, to get around in the metropolitan Dhaka. As a result, further congesting the roads and worsening air pollution, noise, and safety problems. The number of registered motorized vehicle stands at 7, 08,197 in June, 2012 increasing from 3, 03,215 in 2003 (more than 200% increase in less than 9 years) (BRTA, 2012). The alarming trend shows that, the total number of buses remains almost same in this 9 year period, private vehicles, particularly, number of cars and motorcycles more than doubled. Public transport such as buses and minibuses has grown at a very insignificant rate even though the demand for public transport services has increased noticeably. On the contrary, Motorcycles, cars and jeeps/ station wagons constitute around 42%, 25% and 10% of total motorized vehicles respectively. There are 11,060 buses and 8,583 minibuses registered (as of June, 2012) which represent only about 3% of total motorized traffic. Though the number of large buses remained nearly constant, the share of bus fleet has been in fact declining, due to decrease in number of minibuses (BRTA, 2012).

To improve the current situation and reorganize the existing traffic system methodically, the government prepared the Strategic Transport Plan (STP) for Dhaka which recommended a package of comprehensive programs for the development of transport infrastructure over 20 year period. This strategy includes various types of development agenda, such as three Bus Rapid Transit (BRT) routes (Line 1, Line 2, and Line 3), three Mass Rapid Transit (MRT) (Metrorail) routes (Line 4, Line 5, and Line 6), 50 highway projects etc. The implementation program has been divided into four periods of five years each; beginning in 2005 and ending in 2024 (Louis Berger Group and BCL, 2005).

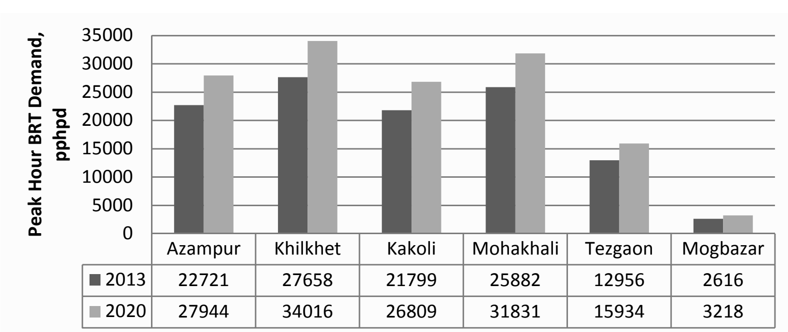
4. CONCEPTUAL PHYSICAL DESIGN OF BRT LINE-3

The BRT line-3 will start from Uttara and end in Phoenix Road (Ramna), covering around 18.5 Km. As the roads of old Dhaka (Allauddin Road, Bangshal Road, etc.) are too narrow to operate BRT, feeder service with small buses will be introduced which will provide service from Sadarghat to Phoenix Road integrating the Sadarghat river terminal with the BRT. So, the international airport as well as railway station situated at Uttara will be connected with Sadarghat river terminal by BRT line 3, hence the development of an integrated transportation system will be accomplished.



	Azampur	Khilkhet	Kakoli	Mohakhali	Tezgaon	Mogbazar
2013	25918	34369	29438	23002	11948	13476
2020	31876	42270	36205	28289	14694	16574

Figure 1: Peak Hour BRT Demand for 2013 and 2020 (To City)



	Azampur	Khilkhet	Kakoli	Mohakhali	Tezgaon	Mogbazar
2013	22721	27658	21799	25882	12956	2616
2020	27944	34016	26809	31831	15934	3218

Figure 2: Peak Hour BRT Demand for 2013 and 2020 (From City)

For estimating the demand of BRT trips, it is considered that the existing buses and para transits are not allowed to operate on the route after opening the BRT.

As a result, all the buses and para-transit passengers will be compelled to shift to BRT. As the non BRT mixed traffic lanes will be free from bus and other para-transit services, it will increase the speed of cars. Due to increase of speed of car, there will be only little modal shifting from the private car to BRT. However, 5% of modal shift from car to BRT is considered under normal pricing policy. In addition, as passengers will be attracted by new BRT service, there will be 7% annual growth rate (close to expected GDP growth rate) in demand over the year 2013. Later, until the year 2020, it is assumed that the annual growth rate will be reduced to 3% (Devcon, 2009). Peak hour BRT passengers' demand estimated for different segment for 2013 and 2020 (to city and from city) is illustrated in Figure 1 and Figure 2. As the BRT line-1 and BRT line-3 will share the same station, it is noticeable that the demand at Azampur and Khilkhet is very high considering the other location. BRT line-1 and Line-3 will split at Kuril. The peak hour demand will be less at Moghbazar and Tezgaon with respect to other location. BRT line-3 will commence from Abdullahpur (Uttara) and end in Ramna with an anticlockwise loop. There will be six main stations (Azampur, Khilkhet, Kakoli, Mohakhali, Tezgaon, and Moghbazar), two terminal stations (Abdullahpur and Ramna) and atleast two sub-stations between two consecutive main stations. The main physical features are illustrated below which are described in a way to satisfy the projected demand of 2020.

4.1 Runway and Pavement Material

The construction of bus way will typically represent approximately 50% of the total infrastructure costs. Lower quality road materials may reduce capital costs but will drastically increase the maintenance costs if roadways need repaving or reconstruction after just a few years of construction. As demand is too high, articulated or double decker bus with high passenger capacity (140-160 passengers) will be selected which will create huge moving loads on the pavement. So instead of flexible pavement, rigid pavement will be a suitable option in the context of longevity, maintenance cost and load bearing capacity. Conversely, flexible pavement often requires resurfacing as often as every two years in tropical climates like Bangladesh. Since bus way does not require the vehicle lane changes, center of the lane which is not used by the wheel, will not be paved. However, in the station and intersection, there will be paving in the middle of the road. Grass will be planted in the centre of the road which can absorb noise up to 40 percent (Ceser et.al., 2007).

4.2 Lane Separation

A steel grill, wall or large landscaped median will provide the most complete protection for the bus way. But when the bus will face operational difficulties and stuck in the middle of the lane blocking the whole BRT lane, cannot leave the corridor for these kinds of facilities. For Uttara-Ramna, BRT lane will be separated by curb separator. The curbing material will be rounded on the bus way side but forms a sharp edge on the mixed traffic lane side. This curb separator will be high enough to dissuade private vehicles to enter in the BRT lane but low enough to allow buses to leave safely the bus way to avoid being blocked.

4.3 Station design

Station Platform Length: Stations will be located at the midsection of the road. So a pedestrian underpass or overpass (foot over bridge) will be provided to the passengers for a safe accessibility from the sidewalk. For the main stations there will be two stopping bays. Nineteen meter will be provided for extra vehicle in queue and fourteen meter will be provided for overtaking purpose. Each bay will be nineteen meter of length.

$$Total\ Length = (19\ meter * Number\ of\ stopping\ bay + 19m + 14m)$$
$$= 19\ meter * 2 + 19m + 14\ m$$
$$= 71m$$

Station Platform Width: Design of a station platform width for six main stations depends on the demand of that particular location. The station will be used for both directional (to city and from city) passengers. The widths of the platform are determined, based on the peak hour passenger demand for the year 2020 (Figure 1 and Figure 2). A brief description of equations and different variable used for calculating the station platform width is given below (Ceser et.al., 2007).

$$W_p = 1 + W_u + W_c + W_{opp} \cdots\cdots\cdots\cdots\cdots (1)$$

Where,

W_p	= Total platform width
1 meter	= Width required for infrastructure
W_u	= Width required for waiting passengers one direction
W_c	= Width required for circulating passengers
	= P_{ph} / 2000 passengers
P_{ph}	= Number of circulating passengers expected per hour
	= 2000 passengers / h (assume)
W_{opp}	= Width required for passengers waiting for vehicles going in other direction.

$$A_w = Q_p/D_{wmax} \cdots\cdots\cdots\cdots\cdots\cdots\cdots (2)$$

Where,

A_w	= Minimum area required for waiting passengers
Q_p	= Maximum number of passengers projected to queue
D_{wmax}	= Capacity of a square meter to hold waiting passengers
	= 3 passengers / m^2

$$Q_p = \sum (PB_i / F_i)$$
$$= \sum P_{bbi}$$

Where,

PB_i = Passengers boarding per hour on BRT route i (i=1 as there is only one route)

F_i = Frequency (BRT vehicles / hour) of line i

P_{bbi} = Average Number of passengers boarding per BRT vehicle on route i.

$$A_w = L_b * W_u \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$
$$A_w = L_b * W_{opp} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where,

L_b = Platform Length (m)

From equation (3), for L_b = 71 meter, W_u can be determined. By using equation (1), (2), (3) and (4) for different Q_p, width of BRT stations platform and other variables of different locations has been determined. Different variable for six stations are tabulated in Table 1 and the typical cross section of Mohakhali and Tezgaon stations are illustrated in Figure 3.

Table 1: Different Station Platform Variables and Width

Station Location	W_u (m)	W_c (m)	W_{opp} (m)	Platform width, W_p (m)	Design Width (m)
Azampur	1.2488	1	1.093	4.342	4.4
Khilkhet	1.657	1	1.33	4.987	5
Kakoli	1.42	1	1.0516	4.472	4.5
Mohakhali	1.107	1	1.248	4.355	4.4
Tezgaon	0.64788	1	0.624	3.272	3.3
Moghbazar	0.6525	1	0.1267	2.779	3

4.4 Corridor Configuration:

In the BRT station location a 2+2 lane will be provided for overtaking purpose. In the midblock section BRT will operate in 1+1 lane. 3+3 lane will be provided for the mix traffic (if available), otherwise 2+2 lane will be provided for mixed traffic. Three meter sidewalk will be provided for the pedestrian. Table 2 illustrates the roadway configuration and present right of way of the BRT route.

Table 2: Corridor Configuration and Right of Way (ROW)

Station Location	BRT Lane	Mixed Traffic Lane	Side walk (m)	Station Width (m)	Lane Separator (m)	Required ROW (m)	Present ROW (m)
Azampur	2+2	2+2	3	4.4	0.5	38.4	42
Khilkhet	2+2	2+2	3	5	0.5	39	42
Kakoli	2+2	2+2	3	4.5	0.5	38.5	46
Mohakhali	2+2	2+2	3	4.4	0.5	38.4	46
Tezgaon	2+2	2+2	3	3.3	0.5	37.2	30
Moghbazar	2+2	2+2	3	3	0.5	37	27-35

5. RESULTS AND DISCUSSION:

The physical features are designed based on the projected BRT passenger demand for the year 2020. In most of the station locations, the required right of way (ROW) for BRT is less than the present ROW. So the BRT system can be implemented without further modification in the road geometry. However, at Tezgaon and Moghbazar, the required ROW is greater than the present ROW, land acquisition will be required on that particular locations. In the midblock section the required ROW is 33.7 m. So land acquisition will be required not only for the station location but also for the midblock section at Moghbazar. Furthermore, BRT-1 will share the station at Azampur and Khilkhet, consequently the station width will be quite wide (4.4 m and 5.0 m respectively). In addition, some physical constraint such as Mohakhali flyover, proposed Moghbazar flyover, level crossing which must be taken into account while designing such BRT route. These physical constraints in this route, are not discuss in these limited scope of the study.

The results presented in this paper are based on the dataset of screen line survey and conceptual design. The actual forecasted demand can be estimated from origin destination survey data and O-D matrix. Further research with origin destination survey dataset and matrix is required to confirm the paper's findings. The work in this paper could be extended to in depth detail analysis of the physical features using proper dataset and considering the physical constraint in this route. From this study, developing countries as well as cities having high passenger demand like Dhaka, can get a preliminary overview of the issues and physical features which must be considered while constructing BRT.

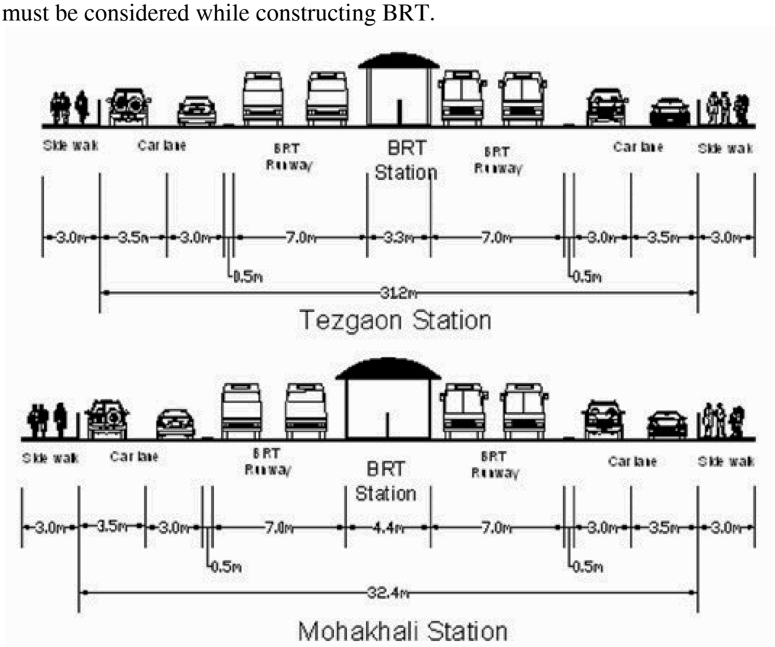


Figure 3: Typical Cross Section of the Stations

6. CONCLUSION

Gradual deterioration of level of service of public transport system, increasing private car ownership, lack of effective road width and transport infrastructure, create acute intolerable congestion in Dhaka. Without proper augmentation and effective use of public transport system, the scenario will become worsen day by day. For proper modal shifting, it is high time to introduce public transport ensuring reliability, accessibility, comfort, safety and economic viability. In these circumstances, BRT is one of the most effective short term solutions because of its high capacity as well as relatively low construction and operating cost. Implementation of BRT within current roadway infrastructure is a key issue in terms of right of way availability, station location, land availability for the terminal and accessibility to the station. Apparently it seems quite complicated to implement BRT within the current road infrastructure. Nevertheless, the results of this paper provide strong evidence that the BRT line-3 can be implemented within the available right of way without doing major modification to the current road geometry. However, in some places some land acquisitions are needed for the successful implementation of BRT.

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Beyond Context Sensitive Solutions: Using Value Sensitive Design to Identify Needed Transit Information Tools

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ABSTRACT

Although the practice of Context Sensitive Solutions instructs transportation designers to respect community values, the focus is typically on the surroundings of the project rather than the direct and indirect stakeholders who will be impacted by a solution. Therefore, the team designing the OneBusAway transit traveler information system turned to the Value Sensitive Design process from information and computer science to help determine what transit rider information tools to build next. Through conceptual, empirical, and technical investigations, the OneBusAway team has developed a list of potential transit information tools and begun to prioritize projects based on the needs of riders of all types, as well as impacts to indirect stakeholders. The use of VSD has helped guide the use of our limited resources, so that they are spent meeting the actual needs of the larger public-transit-using community. The principles of VSD can be applied throughout the transportation industry, especially when considering broader transportation planning goals.

INTRODUCTION

Since the National Environmental Policy Act of 1969, the transportation industry has made significant advances in involving the public in transportation decision-making. With the advent of Context Sensitive Solutions (CSS), this public involvement was taken a step further by encouraging a collaborative approach to design (Newman et al. 2002). As stated in the core principles of CSS, engineers should “Strive towards a shared stakeholder vision to provide a basis for decisions” and “Foster continuing communication and collaboration to achieve consensus” (FHWA 2010).

CSS has been proven to integrate community input while ultimately saving time and money on many projects (Olszak et al. 2008). Although CSS instructs the designer to respect “community values” such as “safety, mobility, and the preservation of scenic, aesthetic, historic, [and] environmental” resources (MSHA 1998), the focus is typically on the physical context, or more so the surroundings, of the project. Value Engineering has been combined with CSS (Osman et al. 2007, Venner et al. 2007) by integrating the monetary value of costs and benefits of the project into the context-sensitive process. However, monetary values only scratch the surface of what matters to a community and the individual members within. Similarly, within CSS, the broad community values as identified by the designer and public processes typically focus only on specific projects. They do not go far enough to integrate the public’s values into design. Therefore, when identifying and designing new transit rider tools for OneBusAway, a transit information system developed for greater Seattle, we employed an approach from information and computer science disciplines called Value Sensitive Design (VSD). In VSD, a designer begins a project by looking at the human values the community possesses, allowing the designer and the public to envision a fuller range of possibilities.

DEFINITION OF VSD AND APPLICATION IN TRANSPORTATION

Value Sensitive Design (VSD) is a principled approach for examining the set of values implicated in an information technology system (Friedman et al. 2006). The “values” in VSD refer to “what a person or group of people consider important in life” – things like freedom, community, or clean air. In order to investigate the impact on people’s values, VSD integrates three types of investigations - conceptual, empirical and technical – in an iterative process. In the conceptual investigation, direct and indirect stakeholders, their values and the tensions among their values are identified. Direct stakeholders are those who interact directly with the final product. Indirect stakeholders are impacted by the product, but do not interact with it. Empirical investigations involve observations, interviews, surveys, literature reviews and measurements of user behavior, all to enhance the designers’ understanding of the values implicated. Finally, technical investigations focus on the technology itself, ideally proactively during the design process.

OneBusAway is not the first application of VSD in the transportation sector. The design of UrbanSim, a widely implemented simulation package for predicting patterns of urban development developed by Paul Waddell, Alan Borning and their colleagues, has been substantially influenced by the VSD methodology (Borning et al. 2008, Borning et al. 2005, Friedman et al. 2008).

APPLICATION OF VSD TO ONEBUSAWAY

OneBusAway is a set of transit tools focused on providing real-time arrival information for Seattle-area bus riders via website (http://onebusaway.org), smart phone applications, phone and text-message (Ferris, et al, 2010). It has existed as a service for transit riders since 2008 with usage growing steadily over time via word of mouth. Although the more than 40,000 unique weekly users suggest it has been a success as a transit information system, the aspirations of the OneBusAway team are much bigger. We hope to develop an information system that can be relied on by transit riders in the many situations they face while using public transportation throughout the region and beyond.

The underlying goal of OneBusAway is to make it easier for riders to use public transportation and thereby increase rider satisfaction and increase transit ridership (Sinha 2003). Although we have developed applications beyond real-time arrivals (Watkins, et al. 2010), to date, the tools offered are based almost completely on our own experiences as riders, rather than on a comprehensive look at the potential user base. Because the developers of OneBusAway represent only a few types of riders on the transit system, we must expand our knowledge of riders' and other stakeholders' values and information needs in order to achieve our goal.

Rather than using VSD to evaluate a specific technological system, we are taking a more open-ended approach. When attempting to answer the question, "What do we build next?" we are faced with a lengthy list of potential applications. Which should we implement? Which would be most valuable to our community? Are we missing an important class of applications? We hope to use the VSD process to help inform these questions.

The general outline of the process undertaken to date can be broken into three major steps: 1) Identify the range of important stakeholders, both direct and indirect. 2) Map the set of benefits, harms, and pertinent values for the different stakeholders in the area of public transit through conceptual and empirical investigations. 3) Generate a list of potential transit applications as guided by the benefits, harms, and values identified in our initial investigations. The remainder of this paper describes in further detail the process outlined above as well as future work.

INITIAL CONCEPTUAL INVESTIGATION

Using the principles of VSD, the OneBusAway team first conducted a conceptual investigation listing groups of direct and indirect stakeholders. The direct stakeholders included various categories of riders, such as riders of different age groups, genders, and socio-economic groups, commuters and non-commuters, choice and captive riders, riders with access issues (blind, deaf, cognitive, wheelchair) and riders with accessories (bike, suitcase, stroller, packages). The indirect stakeholders included non-riders on various other modes, transit employees (bus drivers, general manager, transit planners / schedulers, GIS / data-source employees, field supervisors and dispatchers), and other members of the community (businesses, employers, advocates, citizens, elected officials). A preliminary list of the benefits, harms, and pertinent values for each of these groups was developed. The result of the conceptual investigation was a detailed description of the value trade-offs implicated by transit rider information tools, summarized below.

Many of the tools for OneBusAway, both existing and potential, aim at improving the efficiency and lowering the uncertainty of a rider's interaction with public transit. However, in the process of supporting the values of individual riders, we find these values can be in tension with a variety of other values. Rider **privacy** is an important value that is a source of tension for many of the current and future OneBusAway tools. These tools, from a basic text-message interface to a powerful location-aware smart-phone application, all leave bread-crumbs of personal location data as users interact with the system. Requesting real-time arrival information or planning a trip gives detailed information about the user's current location and travel patterns, raising questions about use and protection of personal information.

Rider **accessibility**, **economic cost**, and **fairness** can be in tension with providing more efficient OneBusAway tools, as many of these potential tools could require increasingly advanced (and expensive) smart-phones. While the set of applications enabled by such devices are exciting, they leave out those riders who either cannot afford these devices or have trouble using them because of visual or other impairments. There is a larger question of fairness if we are developing tools that make public transit easier to use for only a subset of the total transit-using population. This tension can be mitigated by providing tools for a range of platforms (as we do already), but the experience of a user with a simple cell phone is nevertheless probably not as satisfying as that for a user with a smart phone.

There are a number of values that are implicated by system accuracy, including **safety**, **comfort**, and **calmness**. For many of the tools, the end result is a more efficient transit experience *when the tools work correctly*. When the tools do not work correctly, it can make riders' trips take much longer and be more stressful, especially if they miss a bus. As the transit tools push the limits of the available real-time data, we also push the limits of how much confidence each rider can have in the results of the tools. Beyond simple data errors, there is the potential for users to game the system as well, attempting to use crowd-sourced tools to discourage other riders from taking a particular bus and slowing down the route.

Values of transit drivers can sometimes also be in tension with those of riders. Driver **safety** may be an issue for systems that require the driver to manually input vital stats about the bus, such as when the bus is full, when the bike rack is full, or when wheelchair spaces are taken.

The **privacy** of transit drivers and transit agency **reputation** may also be in tension with rider efficiency. Many of the tools that share information about the on-time status of a particular bus or on-time statistics for an entire route may be useful to riders, but they also potentially make more transparent each driver's on-time performance along with the on-time performance of the agency overall. This trade-off is part of the overall tension between rider **trust** and **transparency** in OneBusAway tools and transit agency **accountability**, as building tools that are transparent for riders with regard to underlying transit information might require exposure of more information from the transit agency and hold them to a higher standard of accountability.

Agency **economic** interests may be in tension with rider tools that promote efficiency. These tools may be great for riders, but they can be costly to maintain for transit agencies. Even when third parties, such as the OneBusAway developers, are providing the tools, time and money must be spent preparing and maintaining the transit data feeds that power these tools. In fact, **economic** interests are often in tension with many of the values listed in our analysis, as one of the main road-blocks to potential solutions is often a financial barrier.

OneBusAway already supports the rider value of personal **safety** by providing tools that give real-time arrival information so a rider doesn't have to wait any longer than necessary for a bus. We could go further by providing information about the relative security of particular stops or even broader neighborhoods. While these tools directly address riders' value of **safety**, they may be in tension with rider **trust** and **accountability**, especially when the tools provide information that is incorrect. Furthermore, these tools might be in tension with the values of **community** and **privacy** if they give riders the ability to label stops, other bus-riders, particular drivers, or even entire neighborhoods as "sketchy" or "unsafe".

The value of **sustainability** is a motivating value to provide tools that increase the usability, and as result the overall use, of public transit. However, these values are often in tension with the values of **independence**, **self-respect**, and **self-image**. Many members of the community find a personal car to be more flexible and socially validating than the public transit alternative. A personal car may be easier to use for a broader range of trips or seen as a symbol of status compared with riding the bus.

We have considered developing tools that work to build a social network around transit usage to increase the sense of **community** and **self-image** for transit-riders. However, such social network tools are often in conflict with the value of rider **privacy**, as these tools can potentially share considerable private information about individuals across their social networks.

EMPIRICAL INVESTIGATION

In order to better understand the human values implicated, the second portion of the project was an empirical investigation that built on the conceptual investigation described above. The process included a literature search and review of transit agency rider / non-rider surveys, a group forum and cultural probe with the King County Metro Transit Advisory Committee, and interviews with transit agency personnel. The focus of this empirical investigation was to refine the list of harms, benefits and values, as well as determine the types of transit rider tools that would increase satisfaction and the potential to ride.

Transit Advisory Committee: Bus Riders. The first stakeholder group in the study was the King County Metro (KCM) Transit Advisory Committee (TAC), a volunteer group of 15 transit-riding citizens who meet monthly to advise about future developments and changes to service. This interaction took place at the December 2009 meeting, attended by 10 members of the committee. The attendees ranged greatly in age (twenties to sixties) and transit usage (some commuter, some leisure, some transit dependent) with an about equal gender split.

The interaction with the KCM TAC took the form of a modified futures workshop and cultural probe. In a futures workshop, participants are asked to critique an existing system, then to fantasize about how it could work and finally to think through steps to implementation (Kensing and Madsen 1991). Due to the limited amount of time, the typical futures workshop technique was modified to focus on evaluation of transit with less time devoted to fantasizing and implementation. Instead, more detailed questions leading to improvements were added to the cultural probe. A cultural probe is a kit that is taken home by participants, allowing them to record in some way their experiences related to the system being studied (Gaver et al. 1999). The cultural probe in this case consisted of lists and postcards.

In the group forum we conducted, participants were asked to list their critiques and suggestions for the transit system aloud while these were recorded on a whiteboard. Questions included: What do you like about public transit? What do you hate about public transit? What is unique about how you use transit? What information do you need to ride the bus?

Responses during the group forum tended to focus on the communal and economic benefits and harms of transit. For benefits, over half of the benefits listed involved community improvement or exploration. The remainder focused on the lower costs associated with transit and its environmentally positive aspects. Concerns regarding transit also focused on community issues, but lack of control dominated the list. Participants expressed concern about the unpredictability and unreliability of buses, as well as the limited possibilities inherent to a fixed route/schedule system. When questioned about what the participants felt was unique about the way they use transit, responses included multi-modal variants, complete dependence on transit and riding with children or luggage. In response to the information they needed to ride the bus, real-time information and routing were of primary interest. Further suggestions mentioned way-finding via common landmarks, as well as touch-screen capability.

After this brainstorming session, each participant was left with a packet containing a series of fill-in-the-blank lists and a group of postcards. The lists expanded on the questions asked in the group forum by adding 6 additional questions and instructed respondents to fill in 5 things for each question: What about public transit would you change? What about public transit would you keep the same? What are your tips and tricks for using transit? What frustrations do you have finding that information? What are your favorite websites and which do you find easiest to use?

The preaddressed stamped postcards showed faces with various emotions (smart, disappointed, exhausted, resourceful, confused, annoyed, helpful, calm or peaceful, scared, happy, angry) with the phrase "Today, transit made me feel…" on one side and left space to tell us why on the other side. Examples of the postcards are shown in Figure 1.

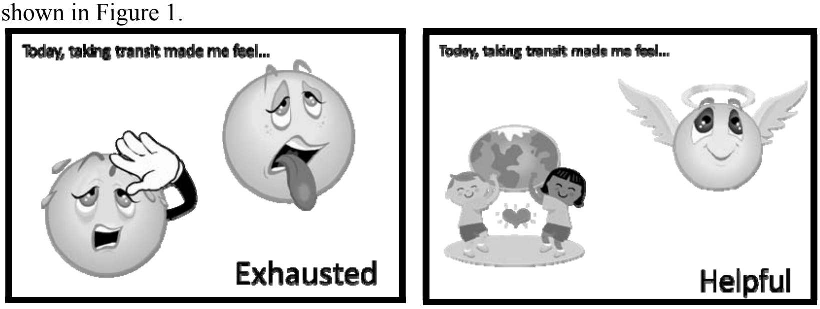

Figure 1. Postcards from the Transit Advisory Committee Cultural Probe.

Within a week of the meeting, responses to the cultural probe began arriving. In total, 8 surveys and 21 postcards were returned. Participants were most diligent in filling out the surveys, providing detailed responses to each of the questions. These responses were perhaps easiest to convert into user needs and desires, as the participants were directly solicited for the benefits and harms associated with their transit riding experience. The benefits expressed were similar to those elicited in the futures workshop, save for an additional benefit of overall system efficiency. Harms were listed in greater detail than those obtained from the group session; however the overall trends remained the same. An additional component was the importance of bus drivers to the overall transit experience. Responses regarding useful information for transit use included communication forms that do not require a smart phone and information regarding the current conditions of an upcoming bus. Relatively few additional insights were obtained from questions that asked for tips and tricks and usable websites, in part due to a lower response rate.

Postcards returned as part of the cultural probe were harder to interpret, but reinforced certain issues that have been brought up in list form. Responses were sometimes detailed: "Today transit made me feel Angry. Surly driver (Rt 66) did not respond to 'Good Morning' and did not call out stops" to brief – "Today transit made me feel WET!". To interpret these postcards, our group attempted to understand the deeper issue behind the feelings expressed by the participants. For example, the "Angry" card suggested that there should be some better means of allowing for communication between riders and drivers (perhaps at times other than in the heat of the moment). However, other cards ("WET!") were simply taken at face value.

Bus Driver Interviews. In addition to the direct stakeholder group forum and cultural probe, we interviewed several key indirect stakeholders in the transit rider tool building process. The intent of these interviews was to obtain information about how rider tools may affect indirect stakeholders, such as bus drivers or other transit employees. In addition to some informal interviews with planning and engineering staff, 6 semi-structured interviews were conducted with bus drivers recruited through the ATU transit union.

At the beginning of the interview, the bus drivers were asked the best and worst things about driving a bus. The best aspects revolved around social interaction and independence. Drivers enjoyed "meeting people you wouldn't normally meet" and being able to "leave their job at work". However, this independence was countered by the worst aspect – management and policy's interference with their job.

Drivers were then asked a series of rider information needs questions. The drivers thought KCM should be providing basic and advanced trip planning components and next bus information. However, the drivers also specifically mentioned providing ways the public can impact the service, fare payment information, and effective rider alerts. One driver commented that "rider alerts should be more effective", including an "interactive system to get the word out about known closures". They made specific suggestions about interior stop announcement signs including alerts and materials to encourage transit access to attractions.

The follow-up included several questions pertaining to their values of safety and privacy. This included their opinions about real-time information, including the value to passengers and the potential violation of their privacy by providing the information as countdown to arrival and historic on-time status for that particular bus.

Some participants thought drivers would adhere to the schedule more if people were more aware of on-time status, but others thought that this might actually make on-time status worse. If drivers are given pressure to stay on-time at all the stops, this may put more pressure on the schedulers as well. The current vehicle location technology was considered not accurate enough, but providing next bus information was considered highly important to riders, especially in the city where "people have options for their wait time". However, caution in the use of real-time information was emphasized because drivers can get back on schedule after a rider has looked at the information. So, riders always need to plan for a couple of minutes before the anticipated arrival time.

None of the drivers saw real-time arrivals as a violation of their privacy and indicated that "it is part of my job to perform in the public eye". However, information about the percent of on-time arrivals historically for a route was seen as a violation of their privacy. Many worried that this would lead to disciplinary action over something the driver is unable to control or increase public confrontation with drivers, such as an in-your-face passenger asking them "Why are you always late?"

TECHNICAL BRAINSTORMING

Through our conceptual and empirical analyses, we have identified a number of harms and benefits arising from various aspects of public transit that affect the different stakeholders in our study. We are taking a broad look at the set of all potential technical solutions, so that we might make an informed decision about which solution to implement given our limited resources. This is in contrast to a typical method that might focus the study on one specific technical solution that might address one of the identified harms or benefits.

Part of that informed decision process involved constructing an extensive list of potential technical solutions. We generated the list through a brainstorming process guided by the results of our conceptual and empirical investigations. Some of the results are directly translatable into technical solutions. For example, the "Information Tools" sections of our cultural probes study solicited feedback such as "Trip planning for primary and return trip".

However, not all the results from our conceptual and empirical investigations were immediately translatable to technical solutions. In a list of positive aspects of public transit, one user listed "More social activity - can talk with fellow passengers, children." Here, rather than fixing something wrong with public transit, we can imagine a class of applications that supports the existing positive activity. That led us to suggest an application to support transit social networking, allowing riders with similar interests (mothers with children, a book club) to coordinate their riding.

Of course, users also listed a number of negative aspects of public transit: – "Get rid of rude, surly drivers", "Violence", and "Loud, rowdy passengers" are a couple of examples. These issues could be addressed through a "Rate My Route" application that allows users to provide feedback on various aspects and make decisions about which trips they take based on that feedback. However, such an application is subject to many value tensions discussed previously. Although it may benefit some, the problems may increase for remaining riders. Such an application would have to be designed with careful and continuing VSD process input.

Some problems listed by riders, such as more dedicated right-of-way (ROW) and more frequent buses, are not ones we can fix directly. Though we can't provide more ROW or more buses ourselves, we can turn the problem around, and provide applications that highlight where service is available. This might be a commute calculator application that suggests the level of transit service at various places in the area, or a last call app that notifies you when the last bus of the night is departing.

When our brainstorming process was complete, we had collected a list of over 75 potential applications. We will not discuss the full list of potential applications here. Instead, the list of potential technical applications can be roughly grouped into 7 categories. We discuss those categories below, along with a few examples.

Social Engagement - A number of applications would support increased social interaction and engagement amongst users of public transit. Examples might encourage and enable riders to organize book clubs for riders of a particular route, or allow mothers with children to match their schedules to ride together, creating an ad-hoc social network. Another major application that fell in this category was the set of "Rate my Route" tools. This application would allow riders to rate various aspects of their transit experience: ride quality, the driver, the route, the area, and stops.

Transit-use Incentives - A number of applications worked to encourage riders to use public transit more often or to be more community-minded through various incentive systems. A typical example was an interactive game where riders were awarded points based on how often they used transit. Special "merit badges" would be awarded for completing specific tasks such as "visiting all the light rail stops" or "giving up your seat on a crowded bus to another rider". This category could also use rewards from sponsoring retailers to encourage transit usage.

Trip Planning Tools - A number of applications were suggested to improve the capabilities of trip planners, including over-all usability improvements, and adding new data sources such as historical and real-time performance data.

General Planning Tools - This category of applications supports high-level planning of transit use and, more generally, the impact of transportation in general on the wider community. These applications include calculator applications that allow one to easily visualize the various financial, environmental, social, and traffic congestion impacts of various transportation modes. Such tools might help riders plan a better commute based on various impacts or pick a new place to live entirely.

Maps and Information Tools - Many of the suggested applications focused on improving maps and other information display systems used in public transit. Changes were suggested for route maps to support better local context through detailed street names. A customizable map-maker application was suggested to create maps targeted to certain neighborhoods, tasks, or class of users.

Notifications - Being able to automatically notify riders when their stop is coming up or when their bus is running late were frequently-requested applications. Several applications in this category would offer the ability for riders to notify the transit agency of problems such as buses or stops that needed cleaning.

Accessibility - Many of the applications in our list directly address the issue of improving the accessibility of public transit. They included issues of general accessibility, such as providing features across a variety of mobile devices instead of just smart-phones. They also included specific issues, such as providing tools for blind and deaf-blind riders, and improving the functionality of the paratransit system.

RESULTING APPLICATIONS

The results of the initial round of investigations have left us with a lengthy list of potential tools to develop and a beginning list of how those tools might impact stakeholder values. Recognizing that we do not have the time or resources to develop *all* the specified applications, we have to decide about the prioritization of the various potential applications. While a developer might typically just pursue the application that "seems cool", we would like to follow a more principled prioritization strategy.

Looking to the work of Friedman et al. (2006) for inspiration, our prioritization is using a triangulation of three aspects when making a decision about the relative merits of a particular application: 1) Stakeholder concerns and values impacted, 2) Stakeholder dependence on transit, and 3) Technical feasibility and resources.

Stakeholder concerns and values encompass all the harms, benefits, and values we have identified in our conceptual and empirical analysis and how they are served by a particular application. To continue to assess these, our follow-up work will focus more on the relative importance of various concerns and values amongst our stakeholders. We are evaluating the relative importance in a number of ways. For riders, we are gathering comparative information using an online feedback page at http://onebusaway.ideascale.com/. In addition, as the primary indirect stakeholder group that both strongly impacts the rider experience and is also affected by these new tools, we sent out a survey to 500 bus drivers in July 2010, drawing on the interview results described previously.

Following these surveys, we have begun a value dams and flows analysis (Miller et al. 2007) to conduct the first leg of our triangle - stakeholder concerns and values. In this analysis, value dams would be potential rider information tools or components of those tools that are strongly opposed by a set of stakeholders, even if that group is small. Value flows are potential rider information tools or components of tools that a large percentage of stakeholders would like to see included.

The relative dependence upon transit by the stakeholders implicated in a particular transit application is also an important element in our prioritization. All other things being equal, a solution that benefits a large population of riders will generally be preferred to an application that benefits just a few riders. However, some riders are more dependent on transit than others, and we would like to reflect that in our prioritization. For example, an application that benefits a smaller population of blind riders who are totally reliant on public transit might be prioritized over an application targeted at a larger population of choice riders who are not dependent on public transit at all.

Finally, we consider the technical pragmatics of each solution, including technical feasibility, funding, and availability of software developers. For example, some solutions are more technically difficult to implement, others more expensive. These technical pragmatics are a third factor in our prioritization scheme.

The elements described above do not give a straightforward formula for defining a prioritization of the various transit applications we have proposed. Rather, the prioritization will be a judgment call on the part of the implementers. However, we hope that by calling out the different elements to consider when prioritizing, we can come to a more principled prioritization that does not miss any major aspects of the issues at hand.

As a result of the VSD analysis, the two projects that have been pursued immediately are integration of trip planning with real time arrival information and the integration of service alerts with all transit rider information. In order to pursue the first project, the developer of OneBusAway has partnered with the OpenTripPlanner project to work on an open-source coded trip planner that is capable of integrating real time arrivals. For the second project, the OneBusAway team is working with transit agencies in greater Seattle-Tacoma to improve notification of service alerts and availability of service alert information, including integration into real time arrival information. Both of these projects have been emphasized by bus drivers and riders alike as critical to the transit experience. Neither project is believed to have critical value dams. Finally, both touch on improving the experience for blind riders, who are particularly reliant on receiving accurate and timely information when a bus trip is at all delayed or detoured.

In addition, OneBusAway has renewed a commitment to providing real time arrivals via website, cell phone and text-message, the media which are less expensive and more widely available for riders of lower economic means.

CONCLUSION

Invoking the VSD approach for the design of OneBusAway has significantly changed the overarching goals of the project. Before using the VSD approach, our focus was on developing new tools and many of these tools were for high-end smart phones. We had also considered applications which rate drivers or neighborhoods or provide historical arrival information. These applications were found to have severe value dams because of their potential negative impact on bus drivers and some groups of transit riders. Instead, our emphasis has been placed on providing integrated tools on all media, especially service alert notification and integration.

The consideration of indirect stakeholders has revealed the full spectrum of impact that OneBusAway may potentially have. One of the most significant impacts is the consideration of transit drivers in the design. Through bus driver interviews and value tension analyses, it became apparent that the successes of OneBusAway improvements are strongly affected by their acceptance by drivers, who are the primary interface between riders and the transit system. Further, basic questions of fairness dictate that we should consider the views and values of drivers in any case, as a group strongly affected by such technology. Finally, VSD has allowed for a more systematic design process that scrutinized the original plans for the potential improvements to OneBusAway, allowing for a more comprehensive solution approach.

Although VSD has to date been used primarily in the design of information technology, there are many other applications within the world of transportation where it could be useful. At the core of VSD is the idea that we should systematically identify the values of stakeholders and take time to envision the value tensions that may be created by any design, whether technological or otherwise. OneBusAway, as an application of technology to solve transportation problems, was a natural use of VSD. However, the principles of VSD can be applied throughout the transportation industry, especially when considering broader transportation planning goals.

Context Sensitive Solutions has greatly improved the integration of community values into transportation design, yet its primary focus remains the context or surroundings of a corridor. Moreover, even with the name change to context sensitive "solutions" rather than "design", the focus of the process is still typically on specific projects rather than on overall mobility and access solutions. CSS has allowed us, as transportation engineers and planners, to think beyond the books, but not yet to step outside our box. As we strive for livability, it is imperative that we consider the human values of both the users of the transportation system and the other indirect stakeholders impacted by transportation.

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Designing BRT for Future Rail Conversion: Issues, State Of Practice, and Project Considerations

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ABSTRACT

Although many cities have sought to employ busways and bus rapid transit running ways that can be converted to future light rail operation few cities have done so. This paper will examine the reasons why, and present the barriers and costs associated with such convertible BRT/busway design approaches, with real-world case study examples presented. Also presented will be a set of design considerations and recommendations for those BRT/busway projects that seek such convertibility in their designs.

INTRODUCTION

Several cities, whether as political cover against criticism of rail advocates who see bus rapid transit (BRT) as a lower quality investment, or as a way to lay groundwork for an incremental strategy, have studied BRT designs that could be converted to light rail transit (LRT)when ridership and political support warranted it. Even now, Ottawa is undertaking such a project, as is York's Viva BRT. London is said to be considering a similar phased scheme for various BRT facilities.

In practice, however, only one city has converted and reopened a bus facility so designed for rail operations. This analysis will discuss why this has been a rarity, whether it is possible or practical to do so better than this singular experience and evaluate the cost and engineering implications related to achieving a rail-ready design for BRT.

The paper will focus on the experience of several U.S. cities, particularly San Francisco, and Seattle, with comparisons to other cities in the U.S. and throughout the world to provide additional context. Various scenarios for designing BRT running ways to accommodate future light rail are described, with cost estimates for typical aspects of BRT running way design that must be considered in any later conversion to LRT also presented.

CASE STUDY: SAN FRANCISCO'S APPROACH

San Francisco's experience in evaluating its Geary Avenue Corridor BRT Project is an illustrative example of what cities must consider in designing a BRT running way to accommodate light rail transit (LRT) at some point in the future. San Francisco County's Proposition K specifically envisioned that Geary, one of the busiest corridors in the city, accommodate a "BRT service with exclusive lanes and dedicated stations…designed and built to rail-ready standards." The San Francisco County Transportation Authority (SFCTA) staff concluded earlier that light rail was not financially possible within the provisions of the referendum's 30-year Expenditure Plan and thus drafted the plan in a way that required all center-running BRT design alternatives to be "rail-ready."

Currently, a more detailed design and environmental review of this project is being conducted. Once these are finished and accepted by federal officials, the detailed engineering and construction phases will begin, with opening of revenue service is now scheduled for 2016.

Two center-running alignments with exclusive lanes were selected for detailed "rail-readiness" evaluation using three definitions of rail-readiness. The first definition is a minimal package of design guidelines that would produce an alignment that does not preclude potential conversion to light rail in the future, such as LRT-standard horizontal and vertical clearances, grades, adjacent tangents and turning radii, as well as stations sited at locations that can accommodate a light rail platform (typically 180 feet vs. a typical 120 foot BRT platform).

The second definition goes well beyond this approach, to comprise a series of investments that would lead to potential light rail conversion much more quickly– with less incremental financial expenditure and fewer impacts to nearby businesses and transit riders. This definition includes all the construction and installation associated with the first definition, as well as all surface and subsurface infrastructure, including all trackwork (rail, fasteners and concrete supportive slab); all electrical and communications ductbanks, manholes, catenary pole and substation foundations for traction power cables and train control wiring; ductbanks and concrete boxes for stray-current protection against corrosion; any necessary drainage work; and utilities relocation needed, including work to preserve access by these utilities so as not to interrupt BRT service. This definition considerably narrows the differences between this version of BRT and the cost and construction considerations for light rail.

A third definition used in San Francisco is between these extremes in the range of investments, though closer to the first definition. These three definitions are described in more detail later.

Because of budget constraints as well as the fact that light rail for this corridor was not likely in the near future or even two decades after revenue opening of BRT, the first definition of rail readiness was selected by the SFCTA as the project progresses into more detailed design. The agency was concerned that even though the other definitions' additional up-front investment obviated some construction when any decision was made to convert to LRT, the remaining construction needed for LRT would lead to intolerable time and adverse effects on neighborhood businesses and residences.

A good illustration of these construction-related impacts is in the station platforms needed for both modes. Currently available U.S.-built BRT vehicles have a partial low floor (at 13-14 inches without kneeling), similar to low-floor buses used in traditional bus service. Some BRT models also include doors on both sides of the vehicle to allow boarding from center platforms as indicated in one of the design alternatives for a center-running BRT on Geary. However, LRVs operating in the city employ the older standard floor design, with a floor height of 33 inches. Thus, in order to accommodate future light rail conversion, BRT platforms ideally should be designed so that they can be raised with minimal reconstruction and/or related traffic disruption.

BRT project owners could overcome the disparity of floor heights with one of four strategies. First, civil designers could devise a lower but "raisable" platform; i.e., to accommodate low-floor BRT vehicles initially, which could then be raised to accommodate the higher-floor LRVs sometime in the future.

A second option would be to procure vehicle fleets that could use the same platforms. However, the floors of low-floor LRVs and low-floor BRT buses are sufficiently different that horizontal gap of several inches would necessitate use of bridgeplates for passenger access, particular for those requiring assistance. Moroever, in San Francisco a major investment to retrofit one or more existing rail maintenance shops for low-floor LRVs would be required.

A third option would be to procure standard-floor buses for the BRT service, which serve many of the most successful BRT systems in the world, particularly in South America. However, all of the more stylized BRT vehicles currently available in the U.S. market employ at least a partial low-floor design. In addition, standard floor BRT vehicles would forego the advantages of low-floor operation, including eliminating need for more complicated lifts for compliance with accessibility regulations as well as reduced dwell times with low-floor vehicles at stations.

The final option is to construct separate platforms or sections of the same platform, one with a higher floor boarding section and another with the lower-floor section. This is also the approach many LRT systems use to achieve accessibility in transfers between the street and/or low-floor buses and higher-floor rail systems; the lower section is joined to the higher section by a ramp. Platform lengths and corridor constraints might make this approach infeasible, not to mention the additional costs associated with what in effect are twice as many platforms for the corridor.

OTHER INDUSTRY EXPERIENCE

The difficulties of implementing an incremental corridor development strategy as highlighted in the analysis conducted in San Francisco comports with the experiences of other cities regarding analyses of rail-readiness of BRT running way design. For example, the staff of the Metropolitan Transit Authority of Harris County, Texas (known locally as Houston Metro) after initially considering rail-ready BRT (which it called "guided rapid transit") on four of five lines under development, it returned to an all-LRT policy, which was originally promised to voters there.

Houston Metro staff had repeatedly made representations to the public that the lines can be converted without disruption to service, to include the rail embedded into the corridor and all systems except for the electric traction system (Railway Age, 2005). In the end, however, it abandoned any “rail-readiness” strategy and opted to eliminate the incremental step.

The difficulties of this first step are underscored by the initial design of Seattle’s Downtown Seattle Transit Tunnel (DSTT), which was to accommodate LRT at some point in the future. Of all the cities that have considered conversion from a bus fixed guideway to LRT, only Seattle has actually undertaken it.

Plans to convert the DSTT from its initial bus operations to future rail transit use began during its design in the mid-1980s. Several important rail transit design elements were incorporated at that time, many of which are familiar to this discussion. They include rail-oriented horizontal and vertical geometry requirements, tunnel clearances for LRVs, station platform lengths to accommodate four-car LRV trains, station widths and sizing of structural elements to support LRV loads.

However, LRT technology has changed significantly and in many ways that were not anticipated when the tunnel was designed roughly two decades ago. For example, the conversion, which was completed in late summer 2007, included a new LRT traction power system (with attendant retrofit of grounding and other corrosion protection), track and platform modifications to accommodate low-floor LRVs not available in North America at the time the tunnel was designed, upgraded fire/life safety systems to comply with toughened regulations, improved train control and communications systems to support an integrated joint bus and rail operation. Importantly, the tunnel bed was also lowered to accommodate both low-floor LRVs and buses.

In addition, the bus service that used the DSTT was rerouted to the surface streets of the area during tunnel reconstruction. To minimize these adverse impacts, additional police officers were assigned at key intersections who supplement the police force that was also reassigned to surface bus operations. A large public information campaign was also launched to explain the transition. The cost of these measures combined with the retrofit work exceeded $100 million.

Most recently, Ottawa has announced it will convert its Transitway to light rail, ending in a tunnel downtown. The C$2.1 billion project approved by the city council in May 2012 will run light rail trains in a three-kilometer tunnel under the central business district, and the remaining 12.5-kilometer line will run along the existing Transitway (BRT), thus completely displacing the successful legacy bus service. The LRT line will be high capacity, designed for as many as 25,000 riders per direction during the peak hour (up from 10,000 on the BRT), with platforms in the 13-stations that will be long enough for six-car consists. Some of the bus service will be rerouted during construction of the LRT but service will be substantially less and different from what it was before construction, which will begin before the end of 2012.

Also in Canada, another highly successful BRT line, Viva in York, Ontario, is undergoing its second phase of a three-stage development, called Vivanext, in which the public-private consortium is converting the existing arterial-based service in mixed traffic to run in median lanes of the same streets. Road construction of these new running ways along with new stations began in the fall of 2011, and will be completed street by street through 2014, with anticipated Phase 2 launch date of 2017.

RAIL-READY BRT DESIGN CONSIDERATIONS

Table 1 details the typical design elements for a BRT project where LRT constraints need to be considered and whether BRT or LRT requirements control the design. Table 2 compares important design differences between the two modes.

Table 1. Controlling Design Elements LRT Rail-Ready BRT Running Way Design

Design Element	BRT Controlling	LRT Controlling
Design Speed (based on Geary alignment)		√
Horizontal Geometry		√
Vertical Geometry		√
Gradients		√
Superelevation (above adjacent streetscape)		√
Horizontal Clearances		√
Vertical Clearances		√
Platform (based on Geary assumptions of heights)	√	√
Pavement		√
Stray Current Protection		√
Utility Accommodation		√
Cross Section (based on the vehicle type used in SF)		√

Table 2. Comparison of BRT and LRT Vehicles and Running Ways

Dimension (typical for U.S. industry)	BRT	LRT
Top operational speed	65 mph	55 mph
Vehicle length	30-60 ft.	55-95 ft.
Vehicle width	96-102 in.	96-121 in.
Vehicle height	9.5-11.5 ft.	Approx. 12.5 ft.
Vehicle axle ratings	6.6-13 MT	13 MT
Running way min. width (two lanes)	23 ft.	23.5 ft.

The costs of the three definitions of rail ready BRT design mentioned earlier are explained below. The first definition of BRT running way design comprises an approach that does not preclude future light rail operation; this includes LRT-compatible horizontal and vertical clearances, grades and turning radii. This definition does not assume conversion of the platforms or pre-installation of trackwork or supportive slabs.

In all three definitions of rail readiness, the unit construction and materials cost estimates performed for recent light rail projects in San Francisco are used, because these costs are among the highest for transit infrastructure and thus represents a conservative calculation for differentials between BRT running ways designed for rail readiness and those that are not.

As shown in Table III, the first definition of rail-readiness design (i.e., "does not preclude LRT") will cost $2.8 million more than the baseline cost estimate for a two-lane BRT center-running exclusive running way, or slightly less than a 3% premium. For the second definition of rail readiness, which includes all surface and subsurface infrastructure (e.g., trackwork as well as concrete supportive slab), electrical and communications duct banks, manholes, catenary pole and traction power substation foundations, duct banks and concrete boxes for stray-current protection against corrosion, related drainage and utilities relocation, can increase total project costs by more than $114 million, or nearly 100% more than a comparable baseline center-running BRT running cost estimate without these features. The third definition of rail-readiness, which includes more features than the first definition but not as many as the second, would cost $22.2 million more than the baseline design.

Several costs are completely excluded from this analysis. For example, vehicles, commissioning and testing costs and retrofit of maintenance facilities to accommodate low-floor LRVs, catenary and substation installations are excluded. Ticket vending machines are also ewxcluded because they are assumed to be part of the baseline BRT design.

CHALLENGES FOR CONSTRUCTION

As the Seattle experience suggests, conversion of a BRT line to future rail operation will be undertaken as a series of steps designed to minimize the impact on the existing public transport network and affected businesses and residents.

The most elaborate scenario of preinstalled features to minimize rail conversion presented above would result in the least disruption of BRT and feeder bus service and surrounding neighborhoods during the conversion to light rail. However, significant disruption would still occur. For example, alternative bus routes must be established (or if possible, procedures for buses to utilize the portions of the running way not yet under construction or that have finished reconstruction for rail operations, supplemented by maintenance-of-traffic controls) during LRT conversion. Once this is completed, traction power, train control and LRT-specific communications systems will be installed and the above maintenance-of-traffic procedures and alternative transit operations plans must be implemented with attendant personnel reassignments, additional law enforcement deployments and public information campaigns as noted above in Seattle. Similar public information and traffic strategies are also being employed in York and Ottawa.

In addition, stations are must be modified appropriately to support the chosen LRV technology. The cost analysis previously mentioned assumes that in all definitions of rail-readiness the stations used for the BRT phase of the corridor must be modified or even reconstructed to accommodate LRVs, which are several inches lower to the top of rail in the case of low-floor LRVs and many more inches higher in the case of older car models.

Finally, once the LRVs for the converted service arrive, the traction power system will be energized and tested with the new vehicles. This testing will then transition to revenue service simulations of all systems together, typically six months in duration so that the new line can be commissioned to revenue ready status. At this point the operator will decide whether to discontinue the rerouted bus service, reconfigure it to interconnect with the new LRT service, or be continued as a parallel operation in the network.

The most basic definition of rail-readiness would require several construction steps prior to these already mentioned. For example, prior to the above steps, many utilities that were not relocated as part of the initial BRT construction must be relocated. The ductwork, junction boxes and corrosion protection infrastructure previously mentioned would also be installed after utilities relocation but before reconstruction of stations or installation of rail systems. Depending on the city's infrastructure, this alone could be a massive undertaking, which itself could preclude rail conversion.

Moreover, the disruptive effects of LRT conversion on affected neighborhoods and the ensuing political challenges could sufficiently jeopardize the project, particularly in urban areas. These should not be underestimated—and could explain why no city other than Seattle has ever converted a bus infrastructure to one for light rail. Even in Seattle's case where LRT was a strong likelihood in the future, these conversion impacts are high and due to rapid technological change, unforeseen in many cases. A similar experience has occurred in Ottawa. The cost of the bus-based Transitway was $440 million when it opened in 1983—nearly 30 years ago—and it still must be substantially reconstructed to accommodate LRT.

CONCLUSION

Because of the difficulties in reconstructing public transport facilities in an urban environment and because BRT often attracts ridership beyond expectations, no BRT projects have yet been converted to LRT. Though not a BRT project, retrofit of the DSTT represents the first bus right-of-way to undertake a conversion.

Should city authorities decide to anticipate a future LRT conversion, however, the design and construction of these BRT projects should at a minimum incorporate structural (loading) and horizontal and vertical geometric constraints of LRT. Beyond this and a few other investments, however, the marginal benefits of preinstalling and/or preconstructing additional structures and systems for future LRT alignments are minimal unless all such systems are installed. This most elaborate level of rail ready BRT design would be nearly double the costs of a typical BRT investment—and still does not include all costs of such a future retrofit. Nor does it include the potential disruptions to both existing public transport service or the built environment—and of the light rail vehicles themselves can take three years or more to procure and deliver.

Table 3. Rail Ready/Convertibility Cost Comparisons

Description of Incremental Improvement	Alternative 1	Alternative 2	Alternative 3
Design for Horizontal and vertical geometry	$500,000	$750,000	$750,000
Additional pavement structural section depth	0	$15,000,000	$3,000,000
Utility relocation under Transitway	$0	$15,903,360	$0
Related maintenance of traffic	$0	$5,000,000	$0
Duct Bank	$0	$5,808,000	$5,808,000
Manholes	$0	$89,872	$89,872
Hand holes, Junction boxes, Pull boxes	$0	$168,960	$168,960
Rail installation	0	$11,616,000	0
Special trackwork (turnouts etc.)		$2,800,000	0
Track Drainage (underdrains 10" dia)	0	$3,590,400	$1,500,000
Corrosion protection bonding/grounding	0	$1,056,000	$0
TWC loops and system	0	$1,028,000	$0
Modification of traffic signals, recon of side streets for rail upgrade	0	$2,800,000	$0
Catenary Pole foundations only	$0	$0	$1,000,000
Catenary Poles and OCS	$0	$2,956,800	$0
Substations and TES	0	$0	0
Additional foundation to support LRV Station 150 ft length	$1,200,000	$1,200,000	$1,200,000
Subtotal	$1,700,000	$69,767,392	$13,516,832
Engineering and Administrative costs (above BRT design effort)	$544,000	$22,325,566	$4,325,386
Project Contingency	$544,000	$22,325,566	$4,325,386
Total Additional Cost for Alternative	$2,788,000	$114,418,523	$22,167,605
Pct. Above typical exclusive BRT project cost estimate	2.4%	98.6%	19.1%

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U-CONCEPT VIADUCT – PRECAST SEGMENTAL APPLICATION TO UIJEONGBU LRT PROJECT (SOUTH KOREA)

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ABSTRACT

Uijeongbu City, a major satellite town at the northern outskirts of Seoul, features the first application of U-shape structure design concept viaduct (a SYSTRA license) in South Korea.

SYSTRA carried out Detailed Design of the viaduct and provides Construction Supervision assistance on site.

To mitigate impacts on already congested downtown traffic, viaduct span erection using precast concrete segments erected with Launching Girders was selected as the construction method. This provides convenient and fast installation as a natural complement to the cutting edge technology of U-shape structure concept viaduct.

The SYSTRA design focused on structure optimization and standardization to accommodate both budget and construction sequence constraints for this project located in a dense urban location. The design led to an optimised typical section, with capacity for two tracks, all necessary E&M systems and train operation requirements.

Adjustments on key and end segment lengths enable a very flexible distribution of spanning, without major impact on mould numbers, hence further budget savings.

Keywords: Prefabrication, Precast segmental, U-shape structure concept, LRT, Optimization

INTRODUCTION

The Uijeongbu LRT project is a Build–Transfer-Operate (BTO) Light Rail Transit (LRT) private investment project, contracted by GS Consortium under the framework of the Private Participation in Infrastructure act (PPI) with Uijeongbu City, a major satellite city at the northern outskirts of Seoul.

The Consortium opted for U-shape structure concept solution to build the 11km viaduct section, in order to enhance the aesthetical signature of the civil work outlines and benefit from the U-shape inner section properties for eased E&M and Rolling Stock integration.

Precast segmental construction is typical of the U-shape structure concept and was a major request from the City because it is regarded as a significant benefit for the project to mitigate difficulties due to narrow working areas caused by traffic congestion and a tight schedule for the start of operation service.

PROJECT OVERALL DATA

GENERAL

- Project length : 11 km, (all built as viaduct)
- Stations : 15 passenger stations plus 1 depot
- Station length : 35m
- Light train load (VAL system by Siemens) : 115kN / axle (rubber tire system)
- Car-unit length : 26m / pair
- Construction start : July 2007
- Planned Operation start : August 2011

DESIGN

- Typical simple span : 30m
- Maximum span length (continuous bridge) : 45m
- Maximum span length (FCM bridge) : 70m
- Typical section width : 7.5m
- Maximum section width : 8.5m
- Typical segment length : 3.3m
- Total number spans : 306
- Total number segments : 3216

PRODUCTION

- Mould number :17 (4 types)
- Casting yard production capacity : 10 segments / day
- Stacking capacity : 350 (double layer stacked segments)
- Launching girder : 3 sets (supplied by NRS)
- Standard erection cycle : 3 days / span

DETAILED DESIGN OPTIMIZATION

SECTION OPTIMIZATION

The optimization study and thorough interface review with E&M parties resulted in a reduction of the section width, capable to accommodate the already advanced development of the Rolling Stock system. The section base is a large double U-shape and was preliminarily selected by the client (fig. 1).

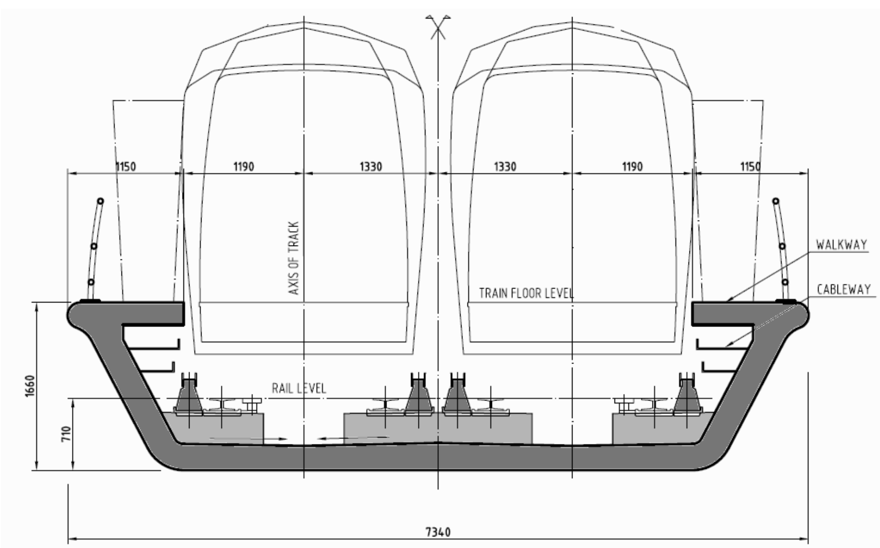

Fig.1 Preliminary E&M interface integration study

All typical E&M system interfaces such as dynamic gauge clearances, power / guidance rail and fixed signalling equipment, located at track level or at viaduct sides were input into the preliminary sections design parameters in order to find an optimum balance between section reduction and maximum safety margin for construction installation, operation and maintenance. The combination of lateral flanges with the U-shape structure, serving as passenger emergency walkways as well as platform edges in stations and the use of inner webs serving as cable tray supports, result in a fully integrated section.

SPAN OPTIMIZATION

Most of the span study focused on standardizing simple span lengths between 30-35m, in order to limit the number of design sections, hence optimizing construction methods, and mould numbers for precast segments. However, due to numerous crossroads encountered by the project alignment which is centred along the city downtown main road network, it was necessary to introduce additional designs such as U-shape structure concept continuous bridge and FCM bridge, to reach necessary minimum spans at overpass areas. These spans range from 45 to 70m.

DETAILED DESIGN OUTPUT

After preliminary sections were set, first calculations led to distribute sections in three different widths (7.5m, 7.9m & 8.5m) in order to mitigate plan alignment curve impact on gauge check (sharpest radius R=60m) and attain minimum compressive resistance sections without requiring excessive higher resistance concrete (72% of total concrete is grade 42MPa).

Span lengths and types were then distributed as follows considering substructure constraints:

Single spans	: 20m to 35m (60% of project length)
Continuous spans	: 22m to 45m (27%)
FCM (free cantilevered)	: 35m to 70m (13%)

The last optimisation efforts focused on standardizing segment length by adjusting key segment and end segment lengths which have a very low impact on the production line.

SIMPLE SPAN

The project is composed of 225 single spans with following section width (fig. 2) distribution:
7.5m (85%), 7.9m (11%) and 8,5m (4%)

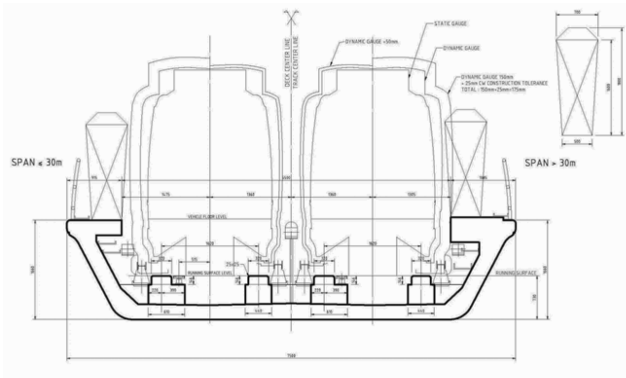

Fig.2 Simple span typical 7.5m wide section

Precast segments lengths vary from 1.85m to 3.3m, with typical length at 3.3m.
The other segment lengths are used to achieve the 12 different span lengths encountered on the project by adjusting length of segments located close to the mid span.

CONTINUOUS STRUCTURES

The project is composed of 35 continuous 2 or 3 span structures.

Larger cross section widths (7.9m - 85% and 8.5m – 15%) than the simple spans (7.5m) have been necessary to accommodate the longer central spans (up to 45m) required for major road crossings, station integration and heavy equipment track crossover loads (stations and crossovers are located on continuous bridges in order to comply with system requirements related with structure expansion length.

The construction method of segment erection by launching girder is similar to the single span structure, with geometry control between adjacent spans implemented by using 100mm cast in place joints using high resistance mortar.

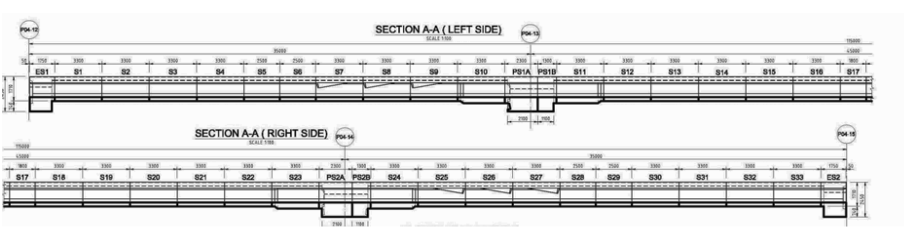

Fig.3 Typical 3-span U-concept continuous bridge (35+45+35) elevation

To account for launching girder erection direction, it was necessary to develop an asymmetrical intermediate pier segment design. as is shown in Fig.3 above,

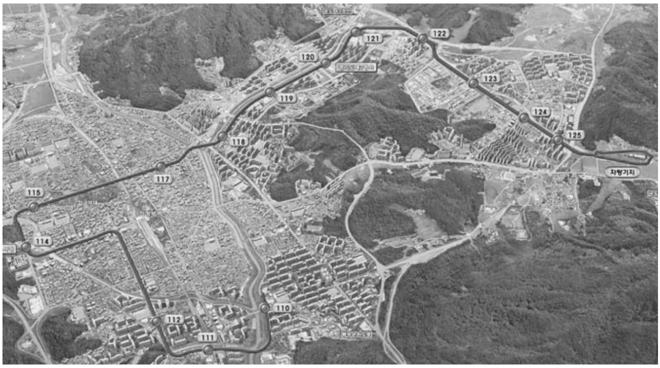

Fig.4 Alignment plan view showing station location and main road crossings

FREE CANTILEVERED STRUCTURES (FCM)

The project includes 11 FCM structures with central span ranging from 45m to 70m (fig. 5 and 6).

These structures have been designed for span lengths greater than 45m (upper limit of continuous structures) or for very sharp plan radius combines with span lengths over 35m, and are constructed of precast segments with 2.5m length, 7.9m width and variable heights.

The design has been standardized in order to maintain a uniform concrete outline and same prestressing layout for the upper U-shape section.

Span length change is achieved simply by removing the segment adjacent to the pier diaphragm from the original longest span case and also removing related unnecessary tendons.

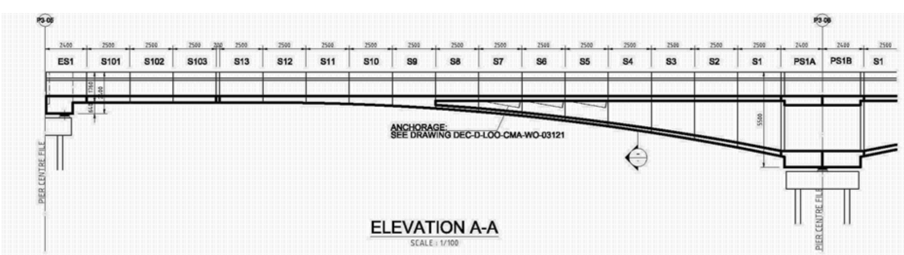

Fig.5 FCM (45+70+45) elevation (end span)

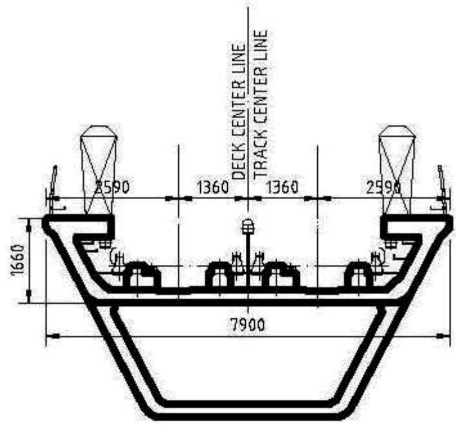

Fig.6 FCM typical section showing continuity of track section outline, while bottom U-box ensures structural integrity

CONSTRUCTION FEEDBACK

CASTING YARD

The casting yard was built nearby the depot area at the end of the project line on a former US Army military base with total area around 3.8 hectares (9.4 acres). It is roughly split into two halves, one for production and the other for stacking segments. Production is distributed among three main lines, with two tower cranes used for transporting rebar jigs to the moulds and three gantry cranes with lifting capacity of 45 to 65 tons for segment handling. An additional stacking yard was later opened to allow more production flexibility.

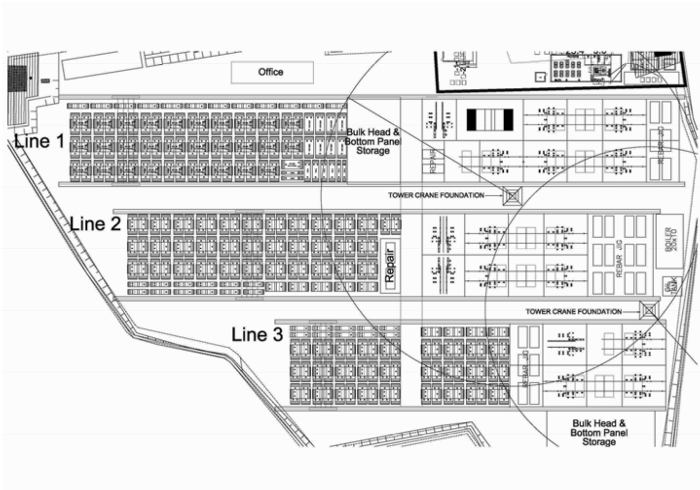

Fig.7 Casting yard general layout

Fig. 8 Casting yard overall view with gantry crane line 1

SITE PHOTO FOCUS

Fig.9 Pier segment lifting (simple span)

Fig.10 Launching girder during positioning stage

Fig. 11 Typical simple span erection completed

CONCLUSIONS

The Uijeongbu LRT U-concept is the first application of precast segmental construction method for light metro project in Korea. It fully achieves its main design objectives and construction advantages through enhanced aesthetical urban integration and fast installation amongst traffic congestioned city road network.

This was possible by optimization of viaduct section and spanning techniques which anticipated E&M system interfaces integration and segment production/erection requirements.

CONSTRUCTION OF A METRO LINE SERVING THE HOLY SITES OF MAKKAH IN THE KINGDOM OF SAUDI ARABIA

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ABSTRACT

Each year, over the course of seven days around 3.5 millions pilgrims gather in Makkah, Kingdom of Saudi Arabia, to perform one of the 5 pillars of the Islam, "El Hajj".

The government (Ministry of Municipal and Rural Affairs) decided to equip the area with a metro line. SYSTRA was involved in the functional design, the result of which was an 18 km metro line with nine stations with line capacity of 72,000 passengers per hour per direction.

The project was awarded as an Engineering, Procurement and Construction contract to CRCC (the Contractor) which decided to award the civil work design to SYSTRA (the Designer) and a local consulting firm.

It was an 8 months fast track design where extensive use of prefabrication was the key.

Keywords: Precast, Pretension, Tensile Membrane, Metro, Makkah

INTRODUCTION

During 7 days of each year around 3.5 millions pilgrims gather in Makkah, Kingdom of Saudi Arabia, to perform one of the 5 pillars of the Islam, “El Hajj”. Makah is the holy city where the “El Kaa’ba” (Great Mosque) is located. At the peripheries of the Makah, three holy regions are the center of specific and complex internal movements between during the 7 days.

Spread through an area of 18 km in length and over 3km in width, the movements during “El Hajj” period became very difficult although there is a developed road infrastructure. KSA government (Ministry of Municipal and Rural Affairs) decided to equip the area with a metro line. SYSTRA was involved in the functional design where the result was an 18 km metro line with 9 stations with line capacity of 72,000 passengers per hour per direction.

The project was awarded as an Engineering, Procurement and Construction contract to CRCC, which decided to award the civil work design to SYSTRA and a local consulting firm.

One of the major characteristics of the project was the tight schedule. CRCC had less than 2 years to construct, equip and deliver the metro line. The target date was a must, and the challenge was won. Operation started actually for the “Hajj” period of year 2010. The 2011 pilgrimage transportations benefited from a full capacity metro system.

SYSTRA tailored a design based on precast methodology as follows:

- In the viaduct area SYSTRA’s concept of precast, pre-tensioned, single U track, 25 m full span erected by crane was a key design element.
- Framing of the nine 340m-long platforms was constituted of 12.5 m precast concrete double T beam.

Time was a real challenge for the project but not the only one. Particular attention was paid to the aesthetics:

- Mitigation of the visual impact of structure thanks to the U-Shape concept, which 150 km have already been designed on various projects worldwide.
- Architectural treatment of the stations: in particular, stations roofs consist of steel framing with tensile architectural membrane so as to match the style of surrounding pilgrims tents.

VIADUCT DESIGN & CONSTRUCTION

Over the metro line length, at-grade sections represent approximately 4.6km. Given the fact that around Muzdalifah holy site, the alignment splits into a North and a South line, 25m apart, the total viaduct length on this project exceeds 17km.

The various deck types utilized to cover this length can be identified as:

- Typical viaduct, 25m-span typical structures forming 90% of the overall length with possibilities to reduce the span length down to 15m to accommodate site constraints.
- Special bridges for long crossings above roads or existing elevated highways. The original design has identified 4 of these long-span bridges.
- Station viaduct extending, in stations, the typical viaduct concept while reducing its span by half.

SYSTRA has striven to propose a design that was both time-efficient and economical for the Contractor on one hand, and Client-oriented and contextual on the other hand, in conveying a strong and unified structural identity from Arafat to Jamarat, the two ends of the project. A general overview of the project is provided in Figure 1, with stations indicated in green color.

Figure 1. General overview of the project

TYPICAL VIADUCT

The U-shaped viaduct, as mentioned above, has been considered as the most adequate concept for the typical viaduct (see typical cross section of viaduct in Figure 2. and prefabrication of a single U deck in Figure 3).

It benefits from inherent assets such as a reduced height (when compared with a traditional box-girder), built-in evacuation path and integration of all system-wide requirements.

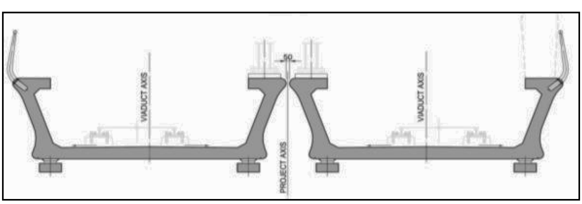

Figure 2. Cross section of typical twin viaducts

It has been associated with the following features:

- Full-span precasting,
- Prestressing by pretension,
- Erection on site with two 300t cranes

Over 800 precast girders have to be produced for the project.

Figure 3. Prefabrication of typical viaduct

On the main part of the alignment, each track is supported by a single U deck, and both rest on hammerhead piers. Every element has been conceived with a focus on standardizing concrete outlines and reinforcement to the greatest extent, while respecting common-practice orders of magnitude in order not to oversize any structure.

Rail elevations and soil conditions have led to only 4 types of shallow and deep foundations. In accordance with the Contractor's requests, only two pier diameters are used for all standard pier heights. Only two sets of concrete outlines have been defined for all pier caps, depending whether they support one track or two.

The standardization and optimization of construction methods go even further in the details of the deck conception. Despite the fact that the girders are longitudinally straight whereas the track itself is curved, rail plinth have been designed with a fixed, enlarged width so as to simplify and speed up the reinforcement process on the precasting yard and to avoid any misplacement or complex identification of every girder.

Figure 4. Erection stages on the line

As for the necessary equipment of the deck regarding metro functionalities such as power supply, signaling, communication, grounding and stray current collection, there again the aim has been to avoid most of the singularities that could have led to delays in the fabrication.

The Civil Works design proceeding, on this project, ahead of the Systems design, provisions have been made to eliminate any possible conception dead end. One illustration of these measures is that every 25m-girder is structurally able to resist the weight and loads of two catenary poles located 12.5m apart on the girder top flange, whereas the typical distance between two poles is 50m in straight alignment.

SPECIAL BRIDGES

Most of the obstacles located along the alignment (roads, buildings, utilities) have been spanned with typical structures. However, other obstacles required special, long-span structures. Three-span arrangements have been developed so as to suit the conditions related to three major highway crossings:

- 27 – 45 – 27m over King Abdullah highway. See Figure 5.
- 35 – 58 – 35m over King Faisal elevated highway. In this area the two tracks are 25m apart, therefore twin bridges are required. See Figure 7.
- 50 – 70 – 50m over Ring Road near Arafat 1 station. See Figure 6.

All four bridges consist of continuous prestressed concrete box-girders. For King Abdullah Overpass, spans are short enough to consider a deck of constant depth. For spans over 50m, variable depth is used for the deck. Construction methodologies also vary: Arafat 1 Bridge is built on integral shoring whereas the others use the balanced cantilever method with form travelers and cast-in-situ concrete segments.

Figure 5. King Abdullah Overpass (27-45-27m) in operation double track, constant depth, balanced cantilever method

Figure 6. Arafat 1 Bridge (50-70-50m) 2 tracks, variable depth, integral shoring

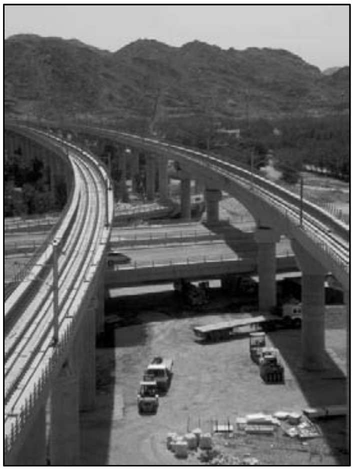

Figure 7. Twin King Faisal Overpasses (35-58-35m)
single track, variable depth, curved, balanced cantilever method

STATIONS

CONCEPTUAL DESIGN

There are nine stations on the alignment. Stations are elevated to minimize visual disruption and the footprint of the stations on the Holy Land. They are sized and optimized to have minimal impact on the environment while allowing for efficient circulation and functioning within.

The output of passenger flow analysis and train operation analysis was a 337.5m platform length where 300m where dedicated to passenger and 37.5m to the technical buildings.

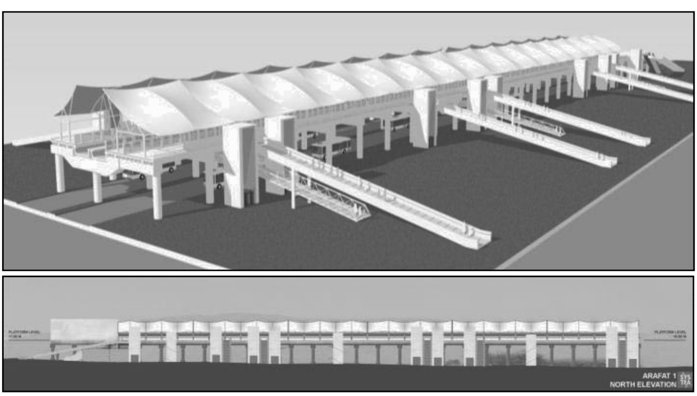

Figure 8. Arafat 1 Station - Perspective & Elevation General View

RAMPS DESIGN

Access to platform level is provided by stepped ramp, which has been designed to be easily negotiated by all pilgrims whether they are aged or carrying baggage. The steps are clearly color contrasted from the ramp sections. Ramps are positioned perpendicular to the platform to minimize the visual impact of the stations on their surroundings. In all stations, stepped ramps are complemented with elevators for disabled persons.

Two types of ramps were designed, concrete ramps to access the platform from ground level and steel ramps to provide a secure passage across the road. The two different types of materials help distinguish the two types of ramps and their function.

CANOPY: DESIGN & MATERIALS

Canopies are designed to integrate well with the mountainous terrain. Organic forms and curves soften their impact on the environment and have the dual function of avoiding sand deposits.

Materials for the canopy element were chosen for their durability in the sometimes harsh climate and their recyclability.

Steel structural elements give a light and elegant form comparable with the canopy of a forest, branching out from the columns. The roof opens towards the middle allowing for free and natural ventilation.

Textile is used for the roof providing protection from the elements especially the hot sun. The textile canopies give the stations a distinct look and integrate well with the surrounding context of textile covered tents (see Figure 9 below).

FINISHES

Main station elements including the platform surface, elevators and steps are finished with locally sourced granite for a natural appearance (see Figure 9).

To provide the station with a distinctly local identity, all guardrails share the same unique motif taken from traditional Islamic art. This is repeated throughout the station and in each station of the line.

Figure 9. Canopy, guardrails and tiling

STATION TYPES: ARAFAT & MINA

The two platforms of Arafat & Mina stations (see Figure 10) have distinct functions. The arrival platform is a free circulation area with a direct connection to the exit ramps. The departure platform is comprised of a waiting area and boarding area.

The preparation / waiting area is designed to accommodate the 3,000 pilgrims who are to board a particular train. The boarding platform has the same capacity. These zones are arranged to allow for easy and organized movements of the boarding passengers. They are arranged on the same level. They are reached by easily stepped ramps. Minimum impact is created at ground level. Platform overflow stairs are provided so as to allow for quicker passenger dispersal for operational / emergency reasons. Large cabin lifts (50 persons) provided at regular intervals provide express delivery to people of reduced mobility.

The alighting platforms are dimensioned so as to allow for quick and easy egress / exit from the station. Similar stepped ramps deliver passengers quickly, safely and easily to ground level.

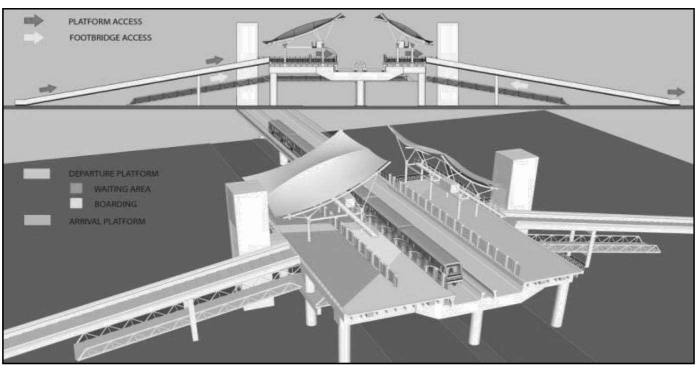

Figure 10. Arafat & Mina Type

Figure 11. Arafat Station – as built

STATION TYPES: MUZDALIFAH TYPE

At Muzdalifah, the Hajj movements generate passenger flows which will board and alight from the same train which moves in the direction of Jamarat. As it is strongly advisable to separate cross flow of this amplitude, the track in the direction of Jamarat has two platforms – one for the boarding passengers, the other for those alighting – they are on either side of the track, on the same level (see Figure 12). The platform screen doors shall open with a time gap allowing the passengers to alight before boarding commences.

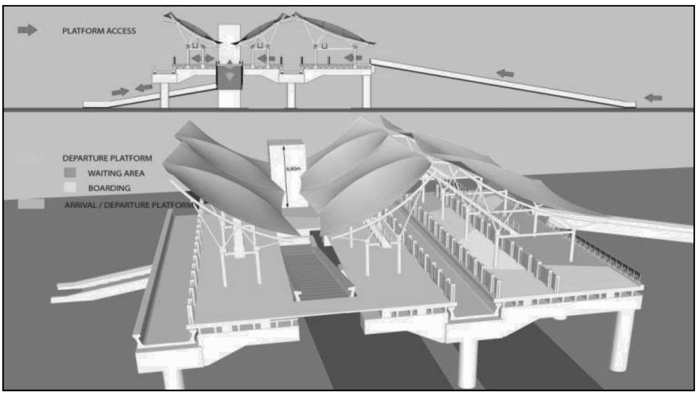

Figure 12. Muzdalifah Type

Figure 13. Muzdalifah Station – as built

JAMARAT STATION

A location-specific design is necessary for Jamarat station where the interaction between the Jamarat Bridge (4th level ramp) and Jamarat station is fully optimized. The principles as described in Figure 14.

- From Jamarat station to Jamarat Bridge ramp:

Two directions are possible. The first by using the western ramp which is connected directly to the Jamarat Bridge 4th level ramp or take the eastern ramps to reach the road level and go through the alighting corridor parallel to the road of king Abdul Azis.

- From Jamarat Bridge ramp to Jamarat station:

After Jamarat Bridge crossing pilgrims can access to the Jamarat station using the crossing road ramp to reach the ground level of the station where they can access to the platform.

Figure 14. Jamarat Station – arrivals & departures movements

CONCLUSIONS

A particular attention has been brought throughout the design process to meeting the deadlines imposed by a very tight construction schedule. Standardization and prefabrication have allowed overcoming the challenge of bringing the project from feasibility stage up to construction stage in just 8 months.

The results of this design effort are aesthetically pleasing guideways and stations meeting the needs of Hajj pilgrims while fitting the local style and bringing a signature project into the Makkah area.

Sustainable Solutions for Railroad Trackwork

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Abstract
The awareness of climate change has become a focal point of scientific development in the 21st century. Both producers and consumers have been trying to reduce the carbon footprint of human activity, and this has led to the increased use of sustainable solutions. These sustainable solutions can be described in two groups: pre-consumption, using renewable resources, such as bamboo; or post-consumption, such as recycled plastics. Both of these types of solutions result in lower carbon footprint emissions and reduce impact on climate change.

Given the higher maintenance costs and destructive nature of using wood ties, there is the potential to utilize a more sustainable material.

HDPE ties are composed of recycled plastic offering both performance and environmental advantages for use as railroad crossties versus the widely used wood ties that are often troublesome in warm, moist soils, where biological organisms can attack wood ties and greatly shortening their service life. Plastic crossties have the ability to divert considerable amounts of waste from landfills if used on the several million crossties that are replaced each year by the railroads. This paper examines the future of plastic ties, utilizing several case studies.

Introduction
For the past 180 years, railroad ties have been made almost exclusively out of wood. In the time since then, the rail industry has made great progress in terms of the speed and safety of trains, however, railroads still face concerns over the use of wooden ties. Rotting, splitting, insect infestations, plate cutting, and spike pulling are hard to detect during a visual inspection, making maintaining the system costly. In addition, these problems have raised several environmental concerns. Despite these life-threatening safety hazards, ninety-two percent of the market still utilizes ties made from soft woods or tropical hardwoods.

Sustainability creates and maintains the conditions under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic and other requirements of present and future generations. Sustainability is important to making sure that we have and will continue to have, the water, materials, and resources to protect human health and our environment ("What is Sustainability", 2012). Therefore, a major problem with the continued use of tropical hardwoods for railroad ties is the acceleration of deforestation throughout the world. According to NASA, at the current rate of destruction, within 100 years, tropical forests will no longer exist. Deforestation has a significant impact on the carbon cycle; the loss of forests releases carbon dioxide into the atmosphere, resulting an increase in global temperatures.

Railroad ties serve the function of not only supporting the rails but also maintaining the proper distance (gauge) of 56.5 inches between rails under expected loads. For a typical railway, ties cannot move more than ±0.125 inches during temperature and load variations. A failure to adequately serve either of these roles can lead to a derailment; endangering both lives and property. Railroad ties are subject to extremely harsh conditions which can compromise their ability to perform expected functions. New, weather-resistant materials are being looked at constantly; plastic is one such material. Railroad ties are subjected to large temperature variations, excessive amounts of ultraviolet light, severe weather conditions, attack from insects, and stresses imposed by use.

In general, a railroad tie must be able to support:

Lateral Load	= 24,000 lbs
Static Vertical Load	= 39,000 lbs
Dynamic Vertical Load	= 140,000 lbs

To effectively withstand such loads, the tie material must possess both stiffness and strength. A railroad tie should, in general, exhibit the following physical properties: (Nosker, Renfree, & Kerstein, 1999).

Compression Modulus	≥ 172,000 psi
Flexural Modulus	≥ 172,000 psi
Compression Yield Stress	≥ 3,000 psi
Compression Strength	≥ 3,000 psi
Flexural Strength	≥ 3,000 psi

To prevent accidents, the material used for manufacturing railroad ties is required to be stiff, strong and resistant to temperature fluctuations, insect infestation, ultraviolet light, while being nonconductive.

Since the rails are to be attached to the ties, the tie material has to be suitable for use with typical types of fasteners, including nails, screws, spikes, and bolts.

Railroad ties originally were manufactured from wood, but can now be found in concrete and steel materials. Wood is still the lowest cost and the most readily available material, but, as previously mentioned, is susceptible to attack from insects which weaken and deteriorate the ties. To compensate for this, wooden railroad ties are often chemically treated to resist such attacks. An example of such chemical treatment is creosote; which only delays attacks and does not completely prevent them. With environmental policies in place, the use of creosote is becoming less and less favorable. Wooden ties are also susceptible to damage from harsh weather conditions and sunlight. Because of these drawbacks, wooden ties require frequent replacement or re-gauging; increasing costs, in materials, labor, and disposal.

Similarly, concrete railroad ties are also susceptible to degrading forces, including abrasion, stress, and strain. In fact, concrete ties have failed prematurely because these ties are generally very stiff. When placed at the standard distance, the ties do not absorb the stress imposed on the rails, thereby forcing the rails to flex more between the ties under load. In order to address this problem, concrete ties are often spaced closer together than wooden ties.

Weather conditions cause damage to both wooden and concrete railroad ties. Water from rain or snow can penetrate into the surface of a wooden or concrete railroad tie. If the tie is then exposed to freezing conditions, the water will expand as it freezes, causing the formation of cracks, thereby weakening the tie. In the case of reinforced concrete ties, such cracks can also lead to oxidation of the reinforcement bars.

Over the years, plastic polymers and plastic composite materials have begun to offer a viable alternative to wood and concrete. Manufactured plastics composites exhibit the necessary stiffness strength, resistance to heat expansion and deformation, increased resistance to degradation from moisture, resistance to sunlight and attacks by insects. Plastic ties also have a longer expected service life; reducing the labor and material costs associated with replacement.

Due to the inherent resistance to insects and moisture, plastic ties do not need additional chemical treatments, eliminating the environmental concerns of creosote treated wood ties.

One disadvantage, however, is the high cost of raw materials for plastic polymers and plastic composites. Polymer resins can be very expensive, making their use economically unfeasible.

Figure 1: Deteriorated wood ties and loose rail spikes after seven years.

Figure 2: Plastic test ties showing no signs of degradation while rail spikes hold steady.

Case Study: Plastic Tie Performance at Rose Yard

In October of 1995, the first ten plastic ties were installed at Rose Yard in Altoona. Pa. The ties were intermingled with twenty wood crossties. To date, twenty-three million gross tons (MGT) have passed over the site at speeds less than fifteen miles per hour. Each tie was periodically examined visually and evaluated and each showed no changes since the installation. The ties were covered in snow for most of the winter seasons due to several severe winter storms, but still showed no signs of weathering.

In 1996, twenty four new composite ties were placed in a fixed degree curve in the FAST track at the American Association of Railroads (AAR) Transportation Technology Center in Pueblo, Colorado. The ties saw one hundred and thirty MGT of traffic at a speed of forty miles per hour for over a year. The ties were visually monitored and show no indication of tie plate cutting or deterioration. The lack of tie plate cutting is very significant in these installations as a typical failure in wood ties and after 900,000 cycles of tens of thousands of pounds force at a predetermined angle the AAR's testing machine broke and there was no evidence of tie plate cutting.

To date, there is no evidence of tie plate cutting, spike loosening, or any other sign of degradation. A test performed in October of 1996, tested six ties installed in mainline service at Milepost 220.41 on Conrail's Pittsburgh Line where track speed is thirty miles per hour with a section of track at a six degree curve and thirty five MGT annually of traffic continued to support a strong case towards plastic composite ties (Nosker, Renfree, & Lynch).

Materials

The following are materials that have been formulated and tried since the first case study utilizing several manufacturing plants for site testing of performance (Lampo, Nosker, Gillespie, and Schriks, 2001).

· Glass-fiber reinforced high-density polyethylene (HDPE)
· Glass-fiber reinforced rubber-modified HDPE

· Polymer-fiber reinforced HDPE
· Styrene and HDPE
· HDPE and mineral by-product combination
· Hybrid steel, concrete, and plastic composite design
· Recycled composites

Manufacturers
There are various compositions of materials for plastic composite ties.

TieTek tie is made from a proprietary mix of plastics, rubber from recycled tires, waste materials, chemical additives, and various fillers and reinforcement agents. Approximately seventy to eighty percent post-consumer waste is currently used in the production of the railroad ties. The ties contain more than 50% HDPE recyclate as well as recycled rubber and mineral fillers (Sullivan, Renne, and Namias, 2009). In August 2001, TieTek enhanced its product by adding a textured finish to its ties. This feature increases the friction with the ballast and prevents lateral movement – particularly in curves – and has been shown to increase the product's advantage over wood ties.

In 1996, Union Pacific installed two TieTek ties. Two hundred and fifty were installed in 1998, two thousand were installed in the year 2000 and ten thousand were installed in a single site in 2001. The company reports that more than fifty thousand TieTek ties are currently in use in the U.S. and worldwide. Customers of the product include Union Pacific Railroad as well as other Class I, short and transit railroads. In early 2000, Union Pacific Railroad placed an order for two hundred thousand TieTek railroad ties for delivery over six years.

In 2005, TieTek produced more than five hundred thousand ties. This level of production consumes approximately two million waste tires and more than fifty million pounds of HDPE recyclate.

US Plastic Lumber produces DuraTie recycled composite ties using its CycleX process, in which plastic waste streams (such as milk cartons, plastic bags and industrial plastic waste) are turned into durable products. Reinforcements, such as glass fiber, can be added during the manufacturing process. Ten thousand of these ties were used on the Chicago Transit Authority (CTA) for a railway track reconstruction project in late 2002.

Polywood, Inc., now currently licensed to Axion International, is the exclusive licensee of a process-to-product immiscible post-consumer HDPE and PS scrap, which was initially developed at Rutgers University and negates the need for glass reinforcement in high load-bearing applications.

Case Study: Improved Material
A Case Study conducted in 2003 at the Transportation Technology Center, Inc. (TTCI) used an in-track test to monitor the performance of plastic composite ties

manufactured by Axion International at the Federal Railroad Administration's (FRA) Transportation Technology Center (TTC) near Pueblo, Colorado. The ties were installed on the High Tonnage Loop (HTL) at the Facility for Accelerated Service Testing (FAST) where they were subjected to over one hundred MGT of thirty nine ton heavy axle load traffic.

Figure 3: Installed Axion International plastic composite ties using traditional wood equipment.

TTCI performed a 2 million cycle test on a Axion International plastic composite tie using an AREMA fourteen inch tie plate with cut spikes and a ten inch rail section.

TTCI considers a minimum of one hundred ties placed under a one hundred MGT load to be the minimum service required to adequately evaluate the in-track performance of ties and fasteners at FAST. This final report documents the performance of a one hundred tie Axion plastic composite tie test zone during one hundred MGT of heavy axle load traffic at FAST.

The test was performed in order to monitor the general performance of the plastic composite tie test zone including the stability of track geometry (vertical profile, and curvature), the ties' ability to resist lateral movement through the ballast section, the gage-spreading strength, and the tie's durability over one hundred MGT.

The tests were performed to the following specifications:

Track Geometry	5-degree, 4-inch superelevation curve
Ballast Section	AREMA 4A Granite - Nominal 18-inch Depth, 15-inch Shoulders
Tie Spacing	19.5-Inch On Center
Fastening System	AREMA 14-inch Tie Plates with Cut Spikes – All Ties Box Anchored
Rail Section	136 lb RE Welded Rail
Train	70 to 80 315,000 lb (39-ton axle load) Cars

Operating Speed	40 mph
Avg. Lead Axle High Rail Lateral Load	About 8 kips
Accumulation of Tonnage	Over 100 MGT Per Year
Climate	Semi-Arid

The ties had an average density of about 53.5 lb/ft^3.

The fastening system used with the plastic composite ties consisted of standard AREMA 14-inch tie plates with cut spikes. All ties were box anchored, using the same fastening system, spike pattern, and rail anchoring as the adjacent wood-tie track.

The 100-tie test zone was installed using standard track construction equipment. With a typical 10-tie transition zone of 8 1/2-foot wood ties installed between the plastic-tie test zone and the concrete tie track.

The first heavy axle load train ran over the newly installed plastic composite tie test zone in the middle of January 2003.

Track gage-spreading strength, single-tie resistance to lateral movement, track geometry retention, and the fastening system were monitored during the test.

Track gage-spreading strength tests were performed at three intervals during the 100-MGT evaluation to quantify the test tie's ability to resist gage-spreading forces. The first test was performed at 0 MGT; the second test was performed after 57 MGT; and the final test was performed after 102 MGT of traffic.

The gage-spreading strength test results indicate that with a 0.5 L/V load the change in gage under 0 MGT was less than 0.25 inch. The gage-spreading strength appears to have leveled out by the second measurement cycle at 57 MGT with a change in gage of about 0.36 inch. The final measurements after the 102 MGT of traffic were within 0.01 inch. Showing no significant gage-spreading strength degradation during the 100 MGT evaluation.

Single Tie Push Tests (STPT's) were performed to quantify tie resistance to lateral movement through the ballast section. The lateral resistance is defined as the force required to displace the tie laterally within one inch through the ballast. Each STPT cycle consists of the average resistance measured on five ties.

To measure the single tie resistance to lateral movement, the test tie was unfastened from the rail and the tie plates were removed. A hydraulic cylinder, fastened to the top surface of the tie, reacts on the rail to push the tie laterally to the high side of the curve.

Data shows that the lateral resistance measured with the plastic ties was similar to that measured with typical wood ties. Some ballast settlement and additional tamping is normal in newly installed track. The 100-tie test zone did not require alignment or vertical profile maintenance and did not exceeding track safety standards.

As installed, there is no evidence of tie plates cutting into the ties. Although there was some initial cut spike uplift, there was no additional uplift during the period of service.

At the conclusion of the test, it was determined that:

- The change in gage spreading between the newly installed measurements and the final measurements was within tolerance limits
- STPT results indicate that the plastic composite ties provided similar resistance to lateral movement of wood ties
- No track alignment or vertical profile maintenance was required in the test zone to comply with track safety standards
- There was no evidence of ballast degradation
- There was no evidence of tie plates cutting into the ties
- No problems with tie skewing
- After some initial cut spike uplift, no additional uplift occurred and therefore no high spike maintenance was required
- The plastic composite ties remained in the HTL

Aside from eight of the plastic composite test ties fractured during spiking ; six into 1/2-inch diameter x 3-inch-deep pilot holes and two into wood plugs. Axion conducted an investigation to determine the cause of the fractures. Immediately identification problem led to the discovery that the ties were produced by one specific machine that was new and was not properly processing the small amount of foaming agent used in the ties

It is noted that this problem is not typical of the Axion ties, and with the remedy of the problem, the ties produced from this machine are now of similar quality to the ties tested earlier (Jimenez, 2003).

The case study shows that the quality and durability of the ties are similar if not better to those that of a wood tie. The cause for concern on the implementation of plastic composite ties is no longer warranted with the extensive studies, tests, and research performed on the life cycle of the plastic composite ties.

	Wood	**Concrete**	**Plastic/Composite**	**Steel**
Unit Cost	$95.00	$225.00	$135.00	$140.00
Ties/Mile	3,250	2,540	3,250	3,250
Cost/Mile	$308,750	$594,000	$438,750	$455,000

Table 1: Cost Comparison of Alternate Crosstie materials

	Concrete		**Plastic/Composite**		**Steel**	
MGT	0º Curve	4º Curve	0º Curve	4º Curve	0º Curve	4º Curve
10	60	53	50	39	55	46
25	51	45	40	33	45.5	39
50	46	45	36	28	41	34.5

Table 2: Service Lives of Alternate Tie Materials in Years

Conclusion

Change has swept the rail industry since the first plastic ties were installed in 1995. In 1990, the ties started out as recycled HDPE. By the mid-1990s, at least two independent groups were developing engineered plastic composite railroad ties using recycled HDPE mixed with other materials for property enhancements. Apart from mechanical property limitations, HDPE offers both performance and environmental advantages for use as railroad crossties. Wood can be particularly troublesome in warm, moist soils, where biological organisms can attack wood ties and greatly shortening their service life. To fight rot and insect attack, wood ties must be pressure-treated with creosote. HDPE needs no such treatment, however, because it is inherently resistant to rot and insects. Also, given that several million crossties are replaced each year by the railroads, and considering the volume of plastic needed to make each tie, considerable amounts of waste plastics could be diverted from landfills and put to beneficial use if plastic crossties were to achieve any significant market penetration.

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PERSONAL RAPID TRANSIT LIVE APPLICATIONS CHALLENGES

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Abstract

Personal Rapid Transit is an energy-efficient, electric transit system with four to six-person vehicles. Working as circulator for job centers, airports, and universities, PRT has a higher average speed than a car. PRT makes carpooling, light rail, commuter rail, and bus more effective, by solving the "last mile problem."

The three established PRT manufacturers are 2getthere, ULTra PRT, and Vectus. 2getthere's system at Masdar City (Abu Dhabi) features 1.1 miles of guideway, five stations, and 13 vehicles. ULTra PRT's system at London Heathrow Airport has 2.4 miles of guideway, three stations, and 21 vehicles. 2getthere and ULTra PRT began passenger operation in late 2010. Vectus is implementing a six-mile, 40 vehicle system at Suncheon Bay, South Korea.

The vendors co-operated to provide joint experiences, with emphasis on planning, designing, constructing, operating, and maintaining the infrastructure and systems. The projects have different characteristics, but also share commonalities.

Introduction

Personal Rapid Transit (PRT), an automated taxi-like service concept, has the qualities to provide the mobility desired in a modern city, while also meeting sustainability requirements of the sustainable city, without having to compromise on any other aspect of the development of the dwelling. PRT offers on demand transport, direct and non-stop to the desired destination. PRT is a new form of public transport offering different capabilities to conventional types such as rail or bus. PRT offers a combination of the characteristics of the personal automobile, the advantages of public transportation (congestion, parking) and clean technologies to ensure a sustainable transit system.

The PRT system functions as a local area network, connecting the locations within its network, and can be particularly attractive as a feeder system to conventional public transit, as well as to parking locations where access to more traditional private transit systems is provided.

There are three established PRT manufacturers: 2getthere, ULTra PRT, and Vectus. Each have an application in operation or realization (see table below).

Company	Application	Length	Stations	Vehicles	Opening
2getthere	Masdar City (UAE)	1.1	5	13	November 28, 2010
ULTra PRT	Heathrow Airport (UK)	2.4	3	21	May 2011
Vectus	Suncheon Bay (SK)	6	2	40	Expected to open mid 2013

The specific characteristics of each PRT system are different on various characteristics. An updated overview of this comparison is maintained on-line at: http://www.advancedtransit.org/advanced-transit/comparison/prt-characteristics/. It will be noted the three systems have many features in common. All of the systems offer major new opportunities for consideration to meet requirements for transport applications. Personal Rapid Transit is attractive in comparison to other options such as cars, taxis and public transport.

Based on the research conducted over the past years, with various papers and studies being available through the Advanced Transit Association's website (http://www.advancedtransit.org/library/papers/), the advantages of PRT are:

1. Shared usage: one PRT car can perform the task of 30 to 40 private cars.
2. Congestion on the network is avoided through dynamic rerouting.
3. Automation leads to predictability, creating safety by avoiding human error.
4. PRT provides direct travel and on-demand service, ensuring trips are quicker, seamless and energy consumption is less.
5. Off-line stations warrant the level of service is not reduced if the number of stations is increased. The station density is limited only by the space available and the cost.
6. PRT guarantees the privacy of the passengers; users can allow other passengers with the same destination to board the PRT vehicle with them, but only at their choice.
7. At off peak times the level of service increases as typically a car will be waiting at the station already.

Although PRT has significant advantages, there are several aspects that need to be addressed to be able to properly configure the system for the city of the future.

Planning

Mobility and accessibility in particular, is an important element for people in the selection of their housing or place of work. Hence a transit system is an integral part of the urban planning. The network needs to be planned to provide the required capacity, while also minimizing its footprint to ensure space can be used for other activities.

To be able to ensure the throughput of any transit system, avoiding the congestion on 'normal' roads and avoiding using the space at grade, leaving it for other activities (such as walking), systems require a dedicated, grade-separated infrastructure (guideway). For Personal Rapid Transit the popular choice is an elevated infrastructure, a result of the costs of underground installation and working within existing spatial planning in build-up areas. The elevated infrastructure ensures that many locations are easily reached. The design of the infrastructure is a vital element to ensure the width and visual intrusion are minimized.

One clear aspect needing to be addressed in the accessibility of the stations. Where cars (and bikes) provide door-to-door transit (if parking is available at both origin and destination), the best effort for PRT requires a network with a high station density. If the walking distances are kept relatively small, accessibility is improved and the network will become more attractive to use for people in the catchment area of a station. This could impact the costs of the network, as stations are not located at grade.

Designing

The transit system is one of many elements within a city, with each element influencing and being influenced by all of the other elements. The PRT network needs to take into account that:

- Stations need to be featured near main attractors of traffic;
- Stations need to be spaced such that the walking distance is minimized;
- The exact location for a station is based on the space available at each location;
- The routes may be restricted by the current spatial planning;
- PRT tracks should preferably be one way;
- The junctions of the PRT network should preferably allow only merge/diverge maneuvers;
- On- and off ramps are required near stations and at turns

The complexity in the design is matching the architectural needs of the city with the attraction of traffic to the characteristics of the PRT system.

In parallel with the design of the route network, the locations of the PRT stations has to be determined, based on the requirement to ensure the maximum accessibility. The design constraints are basically generated by a compromise between opposite goals: achieving maximum coverage and not having an excessive number of stops, which leads to an uniform land coverage.

The network planning is closely related to the dynamic envelope of the system. This again depends on the technology selected. In the case of rail-guided systems the vehicle is wider than the infrastructure (Vectus), while in the case of system using an elevated road (2getthere, ULTra PRT) the actual road is wider than the vehicle. Local regulations can also factor into this: an evacuation path parallel to the track is a requirement in some countries, adding to the width of the system and the difficulty of integrating it into the urban fabric (and minimizing the visual intrusion at grade).

There are different designs of the infrastructure: steel and concrete being the most traditional (and common) choices.

Constructing

The construction of the guide way and the stations is a vital phase. Any problems for the public and the existing services taking place in the implementation environment should be minimized. This means flexibility is required: the ability to fit within the demanding space constraints and the ability for reconfiguration after installation.

Flexibility is an important issue in many developments. Cities are constantly changing and are subject to extensive and extended growth – especially in developing countries. Thus the flexibility to easily reconfigure a transport system to meet new needs is vital. The basic design approach and small scale of all PRT systems provide considerable flexibility. This has been demonstrated in the applications to date

Installation of new Automated People Mover (APM) systems has proven to be a difficult task taking extended time. The installation of the Las Vegas Monorail was a comparatively straightforward installation by APM standards. In this case the time taken from ground breaking in Aug 2001 to initial operation of the 3.9 mile track in July 2004 was just under three years. In other contexts, notably airports and historic city centers, the small space available makes installation of heavy structures complex and expensive.

The disturbance to operations caused by major rebuilding programs is a fact of life for most applications, but nevertheless remains a major issue and is a significant negative factor for larger scale APM systems. By comparison disruption caused by PRT is minimal. This is due to the far smaller scale of the infrastructure which can be largely prefabricated as modules off-site. Although some small scale ground works are inevitable the infrastructure as a whole can be installed in months. PRT offers the opportunity to alter column spacing with the same superstructure to overcome local ground features such as services footways and roadways, and can operate on smaller radius curves such that fitting into existing built environments is more readily achieved. The modular construction also allows elements to be removed and replaced within a short time (such as overnight) as part of route modification or extension.

Stations are perhaps the more complex elements relative to the guide way. A station needs to accommodate the throughput expected, but can also be limited in its footprint and/or shape by the spatial planning in the area of realization. A ‘standard-design’ for a PRT station (one-size-fits-all) is very unlikely and the stations most of the time will be designed to the surroundings. Although the need for multiple station designs can impact the design and construction costs, this is (partly) offset by being able to integrate the system in the most favorable location.

Within stations there are different types of configurations, also dependent on the technology of the PRT system that also influences shape and size. 2getthere and ULTra recommend berths which allow arrival and departure independently from each berth. Vectus use am in-line berth arrangement. The berth layout selected will be a function of the specific application

An important aspect to take into account is station access. With the guideway typically constructed on an elevated level, there is a requirement for either the track to come down or the stations to be constructed elevated as well. Because of the space constraints the spatial planning in existing cities pose, bringing the track to grade level is typically not a option – the length of the guideway to reach ground level becomes restrictive of achieving this. Hence stations are constructed elevated, which means stairs, escalators and elevators need to be integrated – increasing the costs of the system.

There are however opportunities to integrate the stations directly into buildings. With the small cross section of the vehicles combined with low weight, the structural load can be easily accommodated on first or second floors in most buildings. A prime example of this is the station at Heathrow Terminal 5, which has retrospectively been integrated in the existing parking garage. Which means the existing stairs, escalators and elevators can also be used. For commercial buildings, this can generate similar store- front value to these upper floors as is often attributed today to the ground floor.

Operating and Maintaining

Once the system is implemented the operations and maintenance phase commences. This does not only concern the vehicles, but also the infrastructure. It is a system and should be approached as such with proper care being paid to all aspects.

The maintenance of the stations is the most visual aspect. It is the first contact point of the passengers with the system and hence the first point of evaluation of the experience. There is only one chance for a first impression and an unclean, untidy or otherwise negative impression will leave a mark for the system as a whole. For the operations at Rivium, Masdar and Heathrow cleanliness has been taken into account as a key requirement, resulting in positive experiences and feedback. Where cleanliness is perhaps the most important aspect, good way-finding and good functionality of the controls at the stations is vital also. Regular checks on the functionality will need to be performed.

Where the maintenance of the guideway may be less visually impacting, it will have a distinct and clear effect on passengers when not performed properly: the ride quality will suffer. The infrastructure surface of the guideway is an important factor often neglected; it impacts comfort (noise, vibration) and the passenger experience very directly! Although the weight of PRT vehicles is limited, the consistency in driving (maximum normal lateral deviation of 1cm) means that rutting is a potential issue for systems not operating on a rail. A concrete infrastructure would solve this issue, but the longitudinal evenness (or roughness) could be a point of concern, especially as it directly impacts the ride comfort. In addition concrete provides less comfort and more noise hindrance, as well as it is more difficult and expensive to maintain.

Experience 2getthere: Masdar & Rivium

2getthere realized her first APM application, a Group Rapid Transit (GRT) system, at the Rivium businesspark. At this application the track is created at grade and allows for at grade crossings with other traffic. This is only possible as the intensity of both intersecting transit flows is low, allowing for the crossings at grade.

The initial decision to implement the ParkShuttle transportation system between subway station Kralingse Zoom and business park Rivium (city of Capelle aan den IJssel) was taken in 1995. In phase II, the trajectory has been extended and the number of stations increased to 5. The 1800-meter track has three stops within business park Rivium. A new stop has been created to service business park Brainpark III and the residential suburb Fascinatio. The dedicated infrastructure, installed at grade, is now dual lane (with exception of the fore mentioned tunnel and bridge). Several at grade crossings with pedestrian and car traffic are realized.

During peak-hours all vehicles are operational, on-schedule, based on a 2.5 minute interval. The scheduled service ensures the capacity is optimally used, while the on-demand operations in off-peak hours ensure the passenger service is maximized. The business park Rivium case is a good example of the success of Group Rapid Transit applications. The passenger acceptance of the system is great and the experience with the operations of the system recently having been awarded to Connexxion (operating company) for the next 5 years.

2getthere was selected as the supplier for the first phase of Masdar City, providing the link to the Masdar Institute of Science and Technology (MIST) by means of 8 PRT, 2 VIP (leather interior) and 3 FRT vehicles. In this phase the network is approximately 1.5 kilometers long and features 5 stations (2 for passengers, 3 for freight).

The system was the world's first PRT system to open to the public on November 28th, 2010. The short lead time to realization was possible only due to the previous experiences with automated systems – including the installation at Rivium business park.

The system has been getting very good feedback, familiarizing VIP's with these types of systems: royalty and (prime) ministers of various countries, as well as leaders of international organizations (such as the UN) and multi-nationals. During the first year of operations the system availability has been consistently high (>99,4%), leading to a reduction of staff for the next years of operations and further reducing the costs of operations.

Experience ULTra: Heathrow & Amritsar

The Heathrow pod system is in operation at Heathrow airport, London travelling between the Terminal 5 Business Car Park and the main terminal. This system, which started life as a Bristol University project in 1995– was developed by ULTra PRT, now Ultra Global. The pods carry 30,000 passengers every month, and are expected to eliminate 50,000 bus journeys on the roads around Heathrow each year.

The introduction of the first ever Heathrow pod system is in addition to Heathrow's existing £4.8bn investment into improving passenger experience, while reducing the overall environmental impact of the airport's operation.

Operational data show high availability, >99%. This figure is greater than the availability delivered by any other transport system currently operating in London. Of even more significance, passenger response has been exceptionally positive.

John Holland-Kaye, BAA Commercial Director at Heathrow, said: “We’ve been listening carefully to our passengers as part of our plan to make every journey better at Heathrow. Passenger feedback has been amazing and positive Twitter comments abound. We love watching people’s reactions when they see the pods for the first time and then again when they step off just five minutes later at their destination.

The Heathrow pods offer a personal, comfortable and reliable ride that is free of emissions. That’s why our excitement for this pioneering technology is being shared by town planners, architects, other airports, business parks, campuses, retail and residential destinations from the US, Europe, India, Mexico and the UK, who believe that this system could revolutionize transport in urban environments.”

Amritsar: World’s first and largest urban PRT system announced

The Punjab Government has awarded a contract for the world’s first urban Passenger Rapid Transport (PRT) system in Amritsar, India to Ultra Fairwood. The foundation stone for the system was laid by the Punjab Deputy Chief Minister Sukhbir Singh Badal on December 12th 2011. At peak capacity the PRT system will carry up to 100,000 passengers a day on a 8km elevated guideway in over 200 specialist vehicles between seven stations, making it the world’s largest PRT system to date.

Financed entirely by private funding on a build, own, operate transfer (BOOT) basis, the passenger services will go live in 2014. This demonstrates that a large scale urban PRT system can be delivered on a financially viable, fare-based model and offer real returns for financial backers. Amritsar is home to the holiest shrine of Sikhs, the Golden Temple, and is rich in historical, religious and heritage sites. It attracts large numbers of visitors, especially during festivals and religious events, as pilgrims flock to the area. The route takes passengers from the railway and bus stations to the Golden Temple and will take 35% of daily visitors to the Golden

Temple and save up to 30 minutes on the current journey times against competitive fares to alternative modes such as taxis and auto rickshaws.

Ultra Fairwood's CFO and Deputy CEO Alan Moore said "The Punjab Government and city of Amritsar are leading the world in the application of a PRT system to provide volume transport in a major city environment. In one city by installing a PRT system we could potentially reduce a current journey of up to one hour in peak hours to around seven minutes, in another country we may be able to reduce the number of cars on a major city's streets by up to 20%. People are at last starting to understand how this innovative technology can play a role in city transport solutions"

Experience Vectus: Uppsala & Suncheon

The construction of the Vectus Uppsala system was completed mid 2007. It is a test track created for the purpose of verifying and validating all technical parameters, creating a safety case and obtaining relevant authority approvals. It also continues to be a show case. It has been a fully operating system with 3 vehicles, 2-berth station, ticketing and a fully deployed operational and maintenance regime for a 2 year period to obtain first hand passenger experience and operational reliability feedback. Vectus uses a steel rail guide way. At the test track the girders and columns are also steel. After undertaking the initial alignment, there has been no maintenance required at all, except for regular inspections. Wheel wear on vehicles has been minimal. The propulsion system has successfully used Linear Induction Motors (LIMs) to prove operational performance in adverse weather conditions such as snow and ice.

In Suncheon Bay, Vectus is currently installing a 6 mile, 40 vehicle system. Construction is well underway. For reasons of seismic activity, very high wind loads (due to typhoons), combined with poor ground conditions, extensive piling has been required. This involves substantial concrete columns and 30 meter span girders to accommodate a double track with gangway down the centre. Girders are series produced at a temporary site close by the installations; with up to 8 columns currently being completed per week. Steel tracks will be mounted on the concrete girders, providing the interface to the vehicles. Vehicles are electrically powered, via a DC current collection system, for high performance and continuous operation. To make the vehicles as energy efficient as possible, low rolling resistance wheels running on steel tracks are being used, powered by permanent magnet rotary motors.

The stations have 4 in-line berths. The maintenance shop has a minimal footprint, and overnight vehicle storage is carried out in two underground levels accessed via independent lifts.

Conclusions

Personal Rapid Transit (PRT) is a concept which has a considerable history (see: http://www.advancedtransit.org/advanced-transit/history/). It has now reached operational reality. This has demonstrated that PRT does meet its claim of providing on demand, non –stop travel from origin to chosen destination.

Passenger response to the operations at both Masdar and Heathrow has been exceptionally positive. PRT provides a transit experience which delights its users. PRT offers a new mode which can now be considered seriously as part of the transport mix. The network capability offered by PRT complements conventional corridor types of transit, it is designed to take passengers from the major transit hubs to their final destination – making public transit a more attractive alternative and increasing the catchment areas of those stations.

New applications have been announced and more are being considered worldwide. Three companies are offering designed, tested and proven systems. The evidence is that PRT can make a major contribution to solving transport problems in the present Century

PRT Statewide Application:

The Conceptual Design of a Transit System Capable of Serving Essentially All Daily Trips

by

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ABSTRACT

While the State of New Jersey has an extensive commuter railroad, light rail and express and local bus systems, these transit systems serve only 5% of the State's daily work trips and a substantially smaller percentage of the daily non-walking trips. While extensive, these systems are incapable of offering competitive service to the diverse bulk of everyday trips that are spatially and temporally distributed throughout the state. Consequently, these trips are served by the ubiquity and efficient connectivity afforded by the state's roadway system through the use of on-demand personal automobiles. This paper describes attempts to conceptually design a statewide transit system that would afford automobile-like service ubiquitously to essentially all daily non-walking trips. Technologically, the transit system is an area-wide Automated Transit Network (ATN) of auto-sized vehicles offering personalized on-demand non-stop service between all stations, commonly known as a Personal Rapid Transit (PRT) system. Presented is one state-wide design consisting of 8,099 stations interconnected by 16,926 kilometers of one-way guideway in which 215,000 vehicles serve 25 million daily trips.

INTRODUCTION

In the United States and most places in the world, the automobile is the dominant form of transportation. Its ability to provide transport from and to locations within a very short walk of people's desired origins and destinations, the efficient connectivity of the roadway system between those diverse locations and the availability of the automobile when the traveler wants to depart delivers a level-of-service whose spatial and temporal ubiquity isn't matched by any transit system. The only exceptions are in a few niche submarkets such as commuting to work from New Jersey to Manhattan. Here the existing passenger rail system successfully competes with the automobile for patronage. Unfortunately, only 5% of New Jersey's workforce finds itself in such a niche. Except for others that work at home (~4.1%), walk (~2.8%) or the very few that use a bicycle or motor bike (0.8%), the remaining 87.3% use a car to get to and from work. The automobile is even more dominant for non-work trips, allowing its mode share exceed 90% for all trips.

While the automobile has been extremely successful at providing superior mobility to essentially everyone, that market success has had its share of shortcomings. Financially, it is out of the reach of the very poor. Its environmental impacts are substantial. Its dependence on oil has unfortunate geo-political implications. Finally, its personalization and lack of effective mechanisms that could manifest ride sharing, lead to congestion and degraded performance to the many who wish to travel during peak hours.

Automated Transit Networks (ATN, also known as Personal Rapid Transit (PRT) and PodCars) offer the opportunity to provide auto-like on-demand mobility between many locations. Comparable travel times, comfort and convenience are available to all while causing substantially less environmental and physical impacts. The technological components that allow for such a transit system is an interconnect network of guideways that enable vehicles to readily branch and merge between different segments of the network and to bypass intermediate stations so as to offer non-stop trips from any origin to any destination. Short headways (1-3 seconds between vehicles) that allow congestion-free high vehicle flow rates throughout the ATN are achieved through automatic control of the vehicle's throttle and brakes that adheres to a system wide operations management plan that ensures safe, collision-free travel. Branch and merge maneuvers do not become bottlenecks because their functionality is completely on-the-vehicle. The guideway remains completely passive and thus does not impose delays. Ubiquitous accessibility is achieved through the positioning of each of the many off-line stations within a short walking distance of trip generators. Efficient connectivity of all stations is afforded via an interconnected network of exclusive guideways containing no at-grade crossings.

For trips originating and terminating near any pair of the many ATN stations,(say within a five (5) minute walk, (0.4 km)), an ATN system operating with vehicles traveling at modest automobile-like speeds (say about 60 kph) incorporating a vehicle management system that efficiently repositions empty vehicles to where demand is anticipated (so that vehicles wait for rider rather than riders waiting for scheduled vehicles), a competitive automobile-like level of service is delivered by the ATN. While one can readily identify many locations where a small ATN can provide auto-like mobility, the more interesting question: what scale is required of an ATN system such that it can deliver sufficient auto-like service to the majority of the daily trips made throughout a large and diversified regional area, for example a state such as New Jersey? What makes this an interesting question is that by serving such a large percentage of the trips, such a system might provide sufficient mobility such that many, if not most, families would no longer need to own a car as exists in Manhattan today. Walking, the subways, buses and taxis provide accessibility to essentially all trip ends, thus there is no need to own a car and thus the lowest car ownership rate in the nation. How big would an ATN system need to be in order become the dominant mode of personal transportation in the State?

When compared to current mass transit systems[1], ATN offer many advantages. Unlike most existing modes of public transit, ATN would run 24 hours a day and be available on-demand, with the vehicles waiting for riders rather than riders adapting to vehicle schedules. When demand is high ride sharing is used to expand the ATN's capacity to maintain a high level of service. When demand is low, private use of vehicles is offered by default. Travel times can readily be competitive with the current private automobile without the need of excessively high speeds simply because of the non-stop service without transfer feature for essentially all trips. One study estimates that ATN could conceptually achieve between 14 and 65 percent faster average travel speeds than bus, light rail and heavy rail transit.[2] Because the system is fully automated, labor costs such as vehicle control and fare collection are also significantly reduced.[3] Lastly, the recent push to implement clean transportation technology could benefit from the implementation of a ATN system. ATN would use anywhere from 50% to over 80% less energy than conventional public transportation systems as well as have lower noise and pollution impacts on the environment.[4]

The technology required to build ATN systems is currently available. Over the last couple decades, advances in technology have made ATN an increasingly feasible and attractive option. These new technologies include advanced propulsion systems,

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[1] Booz Allen Hamilton and Rutgers University (2005) "Viability of Personal Rapid Transit in New Jersey Study" NJ Department of Transportation Senior Staff Briefing. November 2005. [Presentation, Slide 5]
[2] Carnegie, Jon A. and Paul S. Hoffman (2007) "Viability of Personal Rapid Transit in New Jersey." February 2007. Page 66.
[3] Komerska, Rick (2010) "What is Personal Rapid Transit?" University of Washington. Retrieved online on January 25, 2010 at: http://faculty.washington.edu/jbs/itrans/PRT/Background2.html
[4] Carnegie, Jon A. and Paul S. Hoffman (2007) "Viability of Personal Rapid Transit in New Jersey." February 2007. Page 60.

lightweight materials, on-vehicle switching and guidance mechanisms, and high-speed controls and communication. The network can be readily controlled using an array of coordinated computer systems that monitors and controls all of the vehicles by optimizing routes, controlling speeds, coordinating merges at interchanges and ensuring safety through collision avoidance. While the technology exists and individual mechanisms, sensors and processors continue to perform better as they become cheaper, implementation cost is still a cause of concern. The high uncertainty and consequent risk associated with being a "first adopter" has prevented any state or agency from taking on a major ATN project in North America.

The closest thing to an ATN system currently in place is a small one in Morgantown, WV that serves the West Virginia University community. The only requirement it does not meet is the ability to use the cars for exclusive individual or group use.[5] The Morgantown PRT system, implemented in the 1970's, is comprised of 8.7 miles of guideway and 5 stations, covering a stretch of about 3.6 miles between the farthest stations. The vehicles can fit 8 people sitting, 13 standing, and reach a top speed of 30 mph.[6] Approximately 15 thousand people ride the system every day.[7] The final cost of the system was $126 million, four times higher than was initially expected.[8] This unexpected cost did little to help reduce fears about the risks of implementing a brand new system. Now, decades after the Morgantown PRT was installed, a small system has become operational at Heathrow Airport which carries passengers from a car park to Terminal 5. The scheme cost approximately £25 million.[9] Another small system has also become operational in the new city of Masdar[10]. The interesting aspect of the first year of operation of the Masdar system is its 2.4 average vehicle occupancy. This means, that while auto-sized cars are being used, an average vehicle occupancy that is twice that of the personal automobile is being achieved, making it at least twice as efficient as private automobiles while providing an auto-like level of service.

PRT in New Jersey

In 2004, New Jersey passed a bill to evaluate the viability of implementing a PRT system. The study, done in conjunction with the Alan M. Voorhees Transportation Center at Rutgers University and Booz Allen Hamilton, looked at the current state of PRT technology and the feasibility of implementing PRT in New Jersey. Because a PRT system of the complexity being discussed had never been actually implemented, the researchers guessed that this initial system would require a research and

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[5] Komerska, Rick. "What is Personal Rapid Transit?" University of Washington. Retrieved online on January 25, 2010 at: http://faculty.washington.edu/jbs/itrans/PRT/Background2.html

[6] Schneider, Jerry. "Morgantown Group Rapid Transit (GRT) System." University of Washington. Retrieved online on January 25, 2010 at: http://faculty.washington.edu/jbs/itrans/morg.htm.

[7] "Facts about the PRT." University of West Virginia. Retrieved online on January 25, 2010 at http://transportation.wvu.edu/prt/facts_about_the_prt.

[8] Carnegie, Jon A. and Paul S. Hoffman. "Viability of Personal Rapid Transit in New Jersey." February 2007. Page 67.

[9] Heathrow T5, http://www.ultraglobalprt.com/wheres-it-used/heathrow-t5/

[10] Masdar Year 1 review, http://www.2getthere.eu/?p=990

development program costing about $50-100 million over a three-year period.

The report identified four main types of areas that would best be served by PRT systems. The first was areas with high demand for local circulation, such as regional activity centers or campuses. The goal would be to eventually connect these high demand regions to allow fluid transit between all regions and eliminate the need for personal car use. The second use of a PRT system would be to extend the reach of conventional transit services, such as bus terminals or railway stations, into nearby areas. By doing this, the PRT system is also curbing the need for parking space near the large transportation hub. Thirdly, a PRT system can be a very attractive alternative to personal automobile use in congested areas or areas with limited ability to expand roadway capacity. Lastly, as mentioned before, PRT systems eliminate the need for parking and could be very popular in areas where parking is limited or expensive. Here, the PRT could either replace the automobile or act as an intermediary between the satellite parking location and final destination.[11]

Design of an Area-wide PRT system for New Jersey

The area-wide PRT system for New Jersey was designed so as to serve a majority of the non-walking trips currently made in New Jersey on a typical weekday during the school year. A trip is considered “served” if its origin and destination are both within a short 5 minute walk (400 meters) stations that are interconnected by the network of exclusive guideways. The PRT system is meant to complement New Jersey’s mature commuter bus, light rail, and commuter rail systems that are already in place. These existing systems are integrated into the PRT system by locating PRT station adjacent to existing conventional transit stations so as to create convenient cross-platform transfers. The intention of this new multi-modal area-wide PRT network is to provide auto-like service throughout the entire state so as to largely replace the need to use an automobile, or taxi and completely replace conventional bus operations.

The PRT network design (precise location of each station as well as their efficient interconnection using one-way guideways) was done by students enrolled in Princeton University’s Transportation Systems Analysis class using a suite of interactive graphic design tools. These tools provide instantaneous estimates of the number of trips accessible to the current cursor location as well as a 400 meter circle overlaid on Google (or Bing) aerial photographs to provide a visual perspective of the land use in the service area of this potential station. A mouse click locates a station. Drag and drop tools are also available to readily interconnect the sited stations. Figure 1 shows a small portion of the network in Monmouth County.

[11] Carnegie, Jon A. and Paul S. Hoffman. “Viability of Personal Rapid Transit in New Jersey.” February 2007. Page 65.

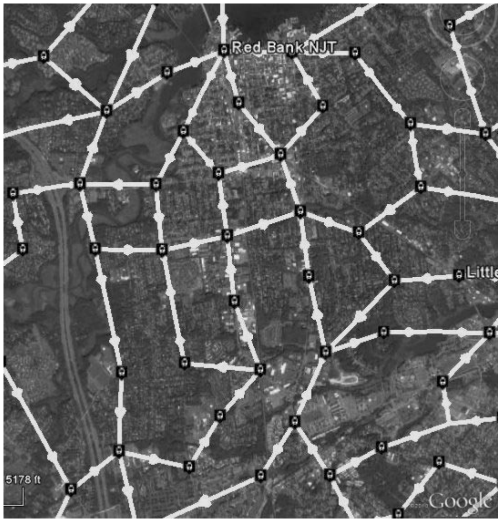

Figure 1. PRT network in a small part of Monmouth County

The underlying trip demand was assimilated from census, education, employment and business patronage data sources. These sources provided data that allowed the daily trip demand to be quantified in total, distributed appropriately throughout the day and assigned a sufficiently precise geographic location so as to enable the computation of meaningful estimates of walk accessibility to the nearest station. Home-based trip ends, were synthesized from census block population data and located at the centroid longitude and latitude of the census bloc. Schools with their enrollments were precisely geocoded to the school's address as were the employment statistics of each business in the state. On site patronage estimates were made for all recreation areas, major and minor shopping centers, dinning places and entertainment and sports venues. These values were also distributed throughout the day so as to assign to each trip a precise departure time. Lastly, the database stored the precise location of every rail transit station in New Jersey, obtained with the aid of Google Earth, and included NJ Transit's latest available typical daily patronage. Once compiled, this database contained precise origin, destination and desired departure time for each of some 32.8 million trips made in New Jersey on a typical weekday. The travel demand characterized by this trip database was used to creatively locate each PRT station and design the area-wide PRT network. A description of the software and data tools used in the process can be found in the Programming Team Report[12] and Kornhauser (2012).

[12] Programming Team Report http://orfe.princeton.edu/~alaink/NJ_PRT_F09/ProgrammingTeamReport.pdf

Each of the above pinpointed land uses was assumed to generate daily trip ends at the rate listed in Table 1.

Table 1. Typical weekday trip-end rates for various land uses

Trip End	Rate
Home	4
Work	3
School	2
Recreation	2
Patronage	2
Transportation	2

The total number of trip ends by landuse type by county is presented in Table 2. Home trip ends represent about half of the total while patron and work trip ends are each a little more than a fifth. Looking at the number of transit trip ends/day, it is obvious that not every county incorporated current bus and train systems into their networks.

Table 2. Typical weekday travel demand in New Jersey in terms of Trip-end type by county

	Trip Type						
County	Home Trip-Ends	Work Trip-Ends	Rec Trip-Ends	School Trip-Ends	Patron Trip-Ends	Transit Trip- Ends	Total Trip-Ends
Atlantic	994,400	188,890	65,503	148,743	524,556	-	1,922,091
Bergen	3,588,768	2,206,530	2,689	572,108	1,834,547	32,087	8,236,728
Burlington	1,712,745	964,091	877	128,185	1,620,722	-	4,426,620
Camden	1,894,259	618,151	3,975	199,431	1,288,468	24,301	4,028,585
Cape May	390,523	66,600	1,394	51,990	130,368	-	640,876
Cumberland	639,939	173,159	70	59,213	374,434	-	1,246,815
Essex	3,263,450	969,984	39,514	253,495	1,217,312	61,545	5,805,301
Glouchester	974,220	235,158	1,184	242,220	106,644	-	1,559,426
Hudson	2,535,040	750,845	38,203	161,461	706,373	229,812	4,421,734
Hunterdon	246,677	121,969	1,510	80,786	574,397	1,575	1,026,914
Mercer	1,360,341	621,590	1,025	195,248	41,171	22,349	2,241,724
Middlesex	1,766,174	4,482,260	10,539	366,902	1,790,574	27,334	8,443,782
Monmouth	2,270,364	428,476	789	206,093	353,113	42,872	3,301,707
Morris	2,191,877	354,296	1,070	161,932	552,982	38,224	3,300,380
Ocean	1,969,107	267,571	972	178,679	72,794	453	2,489,576
Passaic	1,951,207	849,158	71	302,132	698,550	7,939	3,809,057
Salem	215,191	77,837	84	31,205	204,303	-	528,620
Somerset	542,337	959,927	4,971	95,314	836,378	125,632	2,564,560
Sussex	446,080	97,064	733	121,207	154,962	-	820,047
Union	2,021,723	779,063	42,704	169,135	1,045,188	-	4,057,813
Warren	440,848	148,355	95	73,462	180,667	-	843,426
Total	31,415,271	15,360,972	217,971	3,798,941	14,308,504	614,122	65,715,782
% of Total	47.8%	23.4%	0.3%	5.8%	21.8%	0.9%	100.0%

The PRT network was assumed to serve every trip for which both the origin and destination were within a 400 meter walk of a station. NJ-based out-of state work trips were assumed to be served by the PRT system is the home was within 400 meters of a station. The trip was assumed to proceed out of state via the nearest NJ Transit rail of commuter bus Park&Ride. Commuters from out –f state, the reverse logic was used. These trips were assigned to PRT if the employment location was within 400 meters of a PRT station. To determine fleet size, it was assumed that about 15% of all trips were made during peak hours, during which one vehicle could serve about 10 of the trips (likely with occupancy substantially above the average of two). Added was an extra 10% to this number of vehicles, assuming that maintenance would require that not all be working at one time. Below in Tables 3 and 4, summaries of the system infrastructure and number of trips served for one design of an area-wide PRT network are presented. The 8,099 station system interconnected by 10,679 miles of guideway would provide auto-like mobility to 25 million (78.5%) trips on a typical weekday in New Jersey.

Table 3. Stations, Interchanges, Guideway Length and Fleet Size for an Area-wide PRT System

	Infrastructure			
	Stations	Interchanges	G-way (mi)	Fleet Size
Atlantic	215	132	444	4,571
Bergen	1,168	315	594	33,122
Burlington	396	662	322	10,514
Camden	489	418	401	13,290
Cape May	65	19	164	1,040
Cumberland	200	732	494	3,171
Essex	731	623	1,559	23,557
Gloucester	541	256	322	5,748
Hudson	229	205	150	18,043
Hunterdon	310	98	665	2,381
Mercer	366	433	469	7,591
Middlesex	255	180	322	22,124
Monmouth	646	583	1,314	10,702
Morris	298	163	311	9,481
Ocean	631	459	1,076	8,560
Passaic	535	135	334	15,237
Salem	86	331	234	1,399
Somerset	150	143	352	5,910
Sussex	144	217	525	1,882
Union	528	363	305	14,985
Warren	116	131	322	1,748
Total	**8,099**	**6,598**	**10,679**	**215,058**

Table 4. Trips Served by Area-wide PRT System

	Weekday Trips in New Jersey with Area-wide PRT Network				
County	Total Trips/Day	Trip Served by PRT	% Trips Served by PRT	Peak Hour Trips	Median Trips/Station/Day
Atlantic	961,046	539,146	56.1%	80,870	1,289
Bergen	4,118,364	3,906,364	94.9%	585,952	1,719
Burlington	2,213,310	1,239,968	56.0%	185,993	1,609
Camden	2,014,293	1,567,453	77.8%	235,117	1,647
Cape May	320,438	122,676	38.3%	18,401	970
Cumberland	623,408	374,003	60.0%	56,100	961
Essex	2,902,651	2,778,276	95.7%	416,738	1,953
Glouchester	779,713	677,859	86.9%	101,679	644
Hudson	2,210,867	2,127,911	96.2%	319,185	4,775
Hunterdon	513,457	280,867	54.7%	42,130	466
Mercer	1,120,862	895,318	79.9%	134,297	1,257
Middlesex	4,221,891	2,609,291	61.8%	391,392	5,258
Monmouth	1,650,854	1,262,164	76.5%	189,323	1,004
Morris	1,650,190	1,118,175	67.8%	167,725	1,928
Ocean	1,244,788	1,009,559	81.1%	151,433	822
Passaic	1,904,529	1,797,031	94.4%	269,553	1,726
Salem	264,310	165,048	62.4%	24,757	986
Somerset	1,282,280	696,981	54.4%	104,547	2,388
Sussex	410,024	221,855	54.1%	33,299	792
Union	2,028,907	1,767,283	87.1%	265,091	1,720
Warren	421,713	206,112	48.9%	30,918	913
Total	32,857,891	25,363,342	77.2%	3,804,501	1,658

To estimate the cost of implementing this state-wide PRT system, assumptions had to be made about unit costs since such systems have yet to be built in a Public-Private-Partnership framework. Because of the extent of the system it was assumed that a substantial PRT industry had materialized and development cost were considered sunk and not reflected in the cost estimates. Furthermore, public lands are to be used for most guideways and stations so as to minimize the need for eminent domain and the purchase of right-of-way easements. The remaining guideways and stations were incorporated into private lands and existing buildings such that a major fraction of their costs were subsidized by the private land owners who desired the PRT's mobility and accessibility attributes. Nearby places of business subsidized many of the stations. A budget was created using average unit costs for the elements that weren't funded by private entities. It was assumed that an average station cost $2M to build over and above the amenities funded by the nearby businesses. An average kilometer of guideway cost $3.125M. Vehicle cost $100K. The budget is to be financed with bonds that had an 8% interest rate (which currently is very high). Annual maintenance was budgeted at 2% of the capital costs. To calculate annual operating costs, it was assume that vehicle-operating cost was $0.125 per km, average vehicle occupancy, including empty repositioning, was two people, average trip length was eight kilometers, and the annualization rate used to estimate annual total trips served was 300. The yearly cost of the system was the sum of the budgeted cost of capital and the maintenance and operating costs.

Two sources of revenue were considered for the system: fares and station leasing and naming rights. Assumed was a $3 fare for every trip, which is reasonable given that a New York City subway ride costs $2.25. Each station makes $3,000/month in leasing and naming rights. Profit (or loss) was determined by subtracting annual costs from annual revenue.

Table 5 has the financials of the entire system. Total Capital costs, excluding amenities contributed by the privates sector totaled $91 Billion. While several counties lost money from their PRT system, the state as a whole made $2.9B/year based on the assumptions we made.

SUMMARIES BY COUNTY

Summary distribution of trips served by stations in each of New jersey's tewenty-one (21) counties can be found at http://orfe.princeton.edu/~alaink/NJ_PRT_F09/NJPRT09CountySummaries.docx

The above summary also contains links to individual reports providing greater detail about the design ot the PRT network in each of New Jersey's 21 counties.

Table 5 Optimistic Financials for each county as well as the state totals. (last column is P&L per trip)

	Financials						
	Capital Cost (M)	Yearly Cost (M)	Fare Revenue (M)	Station lease and naming rights (M)	Total Annual Revenue (M)	P&L (M)	Cost/Trip
Atlantic	$3,107	$311	$249	$8	$257	($54)	$3.74
Bergen	$8,618	$862	$1,807	$42	$1,849	$987	$1.43
Burlington	$3,453	$345	$573	$14	$588	$242	$1.81
Camden	$4,312	$431	$725	$18	$743	$311	$1.78
Cape May	$1,054	$105	$57	$2	$59	($46)	$5.57
Cumberland	$3,187	$319	$173	$7	$180	($139)	$5.53
Essex	$11,613	$1,161	$1,285	$26	$1,311	$150	$2.71
Gloucester	$3,267	$327	$314	$19	$333	$6	$3.13
Hudson	$3,012	$301	$984	$8	$992	$691	$0.92
Hunterdon	$4,183	$418	$130	$11	$141	($277)	$9.66
Mercer	$3,836	$384	$414	$13	$427	$44	$2.78
Middlesex	$4,332	$433	$1,207	$9	$1,216	$783	$1.08
Monmouth	$8,932	$893	$584	$23	$607	($286)	$4.59
Morris	$3,099	$310	$517	$11	$528	$218	$1.80
Ocean	$7,498	$750	$467	$23	$490	($260)	$4.82
Passaic	$4,264	$426	$831	$19	$850	$424	$1.54
Salem	$1,482	$148	$76	$3	$79	($69)	$5.82
Somerset	$2,651	$265	$322	$5	$328	$63	$2.47
Sussex	$3,101	$310	$103	$5	$108	($202)	$9.06
Union	$4,079	$408	$817	$19	$836	$428	$1.50
Warren	$2,017	$202	$95	$4	$100	($102)	$6.35
Total	**$91,099**	**$9,111**	**$22,827**	**$292**	**$23,119**	**$2,911**	**$1.20**

CONCLUDING REMARKS

The design described above was conducted in 2009/10 academic year. Similar designs were conducted in 2004/5[13], 2005/6[14], 2007/8[15], 2008/9[16] and 2010/11[17]. Each of those studies developed comparable system consisting of some 10,000 stations interconnected with roughly 16,000 kilometers of guideway and able to provide walk accessibility to greater than 80% of trips made in New Jersey on a typical weekday.

This year's class focused on enhancing the process by developing a trip synthesizer that uses the detailed census, school, employment and business patron data sources and synthesizes a typical daily trip chain that starts and ends at home for every New Jersey resident and out-of-state worker. Synthesized for every chain is the precise location of each stop as well as the departure time in hour:minute:second for every trip segment[18]. The synthesis provides a precise spatial and temporal distribution of the 32.8 million trips made in New Jersey on a typical day. This trip data set will enable a mode choice analysis to be done for each of the 32.8 million trips thus identifying all trips that are better served by the PRT network. This will enable a detailed simulation of the operation of the PRT network including an assessment of the propensity for sharing rides during peak demand, the flow of vehicles throughout the network, the assessment of alternative station dispatch strategies as well as alternative approaches to empty vehicle management.

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Bus Rapid Transit (BRT): What is it and Why Do We Need it for Dhaka

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ABSTRACT:

Dhaka, the capital city of Bangladesh, is growing rapidly with an estimated population of over 15 million. The city's transport system is characterised by the critical and deteriorated traffic congestion and the poor public transport services: inefficiency, poor quality of services, lack of reliability and safety for commuters. In addressing the enormous public transport challenges and for achieving sustainable urban transport in Dhaka, the Strategic Transport Plan (STP) suggested the development of six major corridors as mass transit routes including three Bus Rapid Transit (BRT) corridors. In this paper an attempt has been made to discuss the concepts, needs and opportunities of the BRT system. The paper in particular highlights the Dhaka's transport problem characteristics and the potentials of the implementation of BRT system for enhanced and improved public transport services in Dhaka.

1. INTRODUCTION

The prerequisite for economic activity is the mobility of the inhabitants which is catered for by providing the efficient transport system. According to Wright (2003), "Effective public transit is central to development. For the vast majority of developing city residents, public transit is the only practical means to access employment, education and public services, especially when such services are beyond the viable distance of walking or cycling. Unfortunately, the current state of public transit services in developing cities often does little to serve the actual mobility needs of the population. Bus services are too often unreliable, inconvenient and dangerous".

The above comments are essentially cogent in the case of Dhaka's transport system. With huge population of over 15 million, over concentration of both motorized and non-motorized vehicles and that of the mobility, inadequate transportation facilities and policies, varied traffic mix, absence of dependable public transport system and inadequate traffic management practices and parking facilities have created a significant worsening of traffic and environmental problems in Dhaka (Hoque and Alam, 2002).

In spite of low level of motorization, Dhaka suffers from critical and deteriorated traffic congestion largely due to the absolute lack of roads, deficient road network configuration and inefficient traffic management (JBIC, 2000). Existing public transport system, bus transit operations in particular is characterized as far short of the desirable mobility needs of the people in terms of reliability, comfort speed and safety. In Dhaka, buses are generally considered unreliable and time consuming to reach the destination. Thus, there is need to develop a system to give priority and dedicated road space to buses in order to make them reliable and faster. Bus rapid transit (BRT) is considered by the policymakers and public transport specialists as an effective way to improve bus transit services. Today, the BRT concept has increasingly implemented by cities looking for cost-effective transit solutions and has emerged as an economical transit alternative with significant potential for developing countries (Wright, 2003). This paper introduces the concept of BRT system and discusses its relevance and potential to enhance and improve the quality of public transport services in metro Dhaka. The paper has been based on extensive review of the published literature and the information gleaned by the authors from the ongoing BRT Project in Dhaka.

2. BRT: CONCEPTS AND FEATURES

A review of the international published literature revealed that increasing levels of urban congestion have created the need for new transportation solutions. A creative, emerging public transit solution has now been regarded as the Bus Rapid Transit (BRT) system. The definitions, essential features and operational aspects of the BRT system are briefly discussed in this section.

2.1 What is BRT

BRT has been defined as a corridor in which buses operate on a dedicated right-of-way such as a busway or a bus lane reserved for buses on a major arterial road or freeway. Although this definition describes many existing BRT systems, it does not capture the other features that have made it so attractive around the world. BRT has also been defined as a bus-based, rapid-transit service with a completely dedicated right-of-way and on-line stops or stations, much like LRT. This is consistent with the definition of BRT by the U.S. Federal Transit Administration (FTA), as “a rapid mode of transportation that can combine the quality of rail transit and the flexibility of buses” (Levinson et. al., 2003; Thomas, 2001).

In brief, BRT is a fully integrated system of facilities, services, and amenities that are designed to improve the speed, reliability, and identity of bus transit with greater operating flexibility and potentially lower capital and operating costs. BRT vehicles (buses) operate totally on exclusive or protected rights-of-way, the level of service provided can be similar to that of full Metrorail rapid transit. Often, a relatively small investment in dedicated guide-ways can provide regional rapid transit. (Levinson et. al., 2003)

2.2 Why BRT

BRT can be an extremely cost-effective way of providing high-quality, high performance transit. Advancements in technology such as clean air vehicles, low-floor vehicles, and electronic and mechanical guidance systems have made BRT a more attractive transit alternative to both transit users and transportation-planning officials. Bus Rapid Transit (BRT) combines the benefits of light rail transit with the flexibility and efficiency of bus transit. Developing countries with high transit-dependent populations and limited financial resources have increasingly attempted the use of BRT systems because of their low costs and relatively fast implementation times. The cost of a BRT project is considered to be approximately one-third of a LRT project, which is a cost that developing countries can afford. BRT can be integrated into urban and suburban environments in ways that foster economic development and transit and pedestrian friendly design. The World Bank even considers that BRT "can enable new categories of passengers, including more women and children, to benefit from an improved level of safe, accessible and reliable public transport (Rickert, 2010). Typical BRT operations in developing cities are shown in Figure 1 and Figure 2.

Figure 1: Guangzhou BRT (China)

Importantly BRT can have both the short and long term impacts (Tiwari, 2009) as follows:

In the short Term:

- Congestion free movements to majority people.
- Improve safety and convenience of public transport users, pedestrians, bicycles and rickshaws.
- Move out buses from congestion.
- Current modal shares can be maintained.

In the long Term:

- Increase in public transport users, pedestrians, bicycles and rickshaws is possible.
- Reduction in vehicular emissions because of smoother driving cycle

2.3 BRT as High Performance Transit

Several reasons were cited repeatedly in the case studies for considering BRT as a potential high-performance transit investment (Levinson et. al., 2003). Of significance of those are:

(a) Given the costs and community impacts associated with major road construction, improved and expanded public transit emerges as an important way to provide the needed transportation capacity. For a given distance of dedicated running way, BRT is generally less costly to build and equip than rail transit. There are even relatively low facility costs where BRT vehicles operate on existing bus-only or HOV lanes or in mixed traffic. On the other hand, BRT is well suited to cost-effectively extend the reach of existing rail transit lines by providing feeder services to areas where densities are currently too low to support rail transit.

(b) BRT can be cost-effective in serving a broad variety of urban and suburban environments. BRT vehicles can operate on streets, freeway medians, railroad rights of way, arterial structures, and underground. BRT can easily and inexpensively provide a broad array of express, limited-stop, and local all-stop services on a single facility. Moreover, it can often be implemented quickly and incrementally without precluding future rail investment if and when it is warranted. It can also have relatively low operations and maintenance costs. This is primarily because the relatively low fixed maintenance costs can offset variable driver costs.

(c) Like other forms of rapid transit, BRT can be integrated into urban and suburban environments in ways that foster economic development and transit- and pedestrian friendly design. Examples of regions that have integrated BRT successfully include Adelaide, Boston, Ottawa, and Brisbane. It can also be considered an important element of a greenhouse gas reduction policy (Wright and Fulton, 2005).

2.4 Key Features of BRT

Some of the main features of BRT include (Levinson et. al., 2003; Leal and Bertini, 2003; Kulyk and Hardy, 2003):

- Dedicated right-of-ways, priority at signalized intersections and less congestion
- Attractive stations and well designated limited bus stops where integration with other modes of transportation is available.
- Distinctive easy-to-board vehicles and ease of access for disadvantaged people
- Simple, fast and off-vehicle fare collection, use of ITS technologies for optimized performance. In general, Good customer service and safety systems
- Frequent all-day service (should operate at least 16 hours each day, with peak headways of 10 minutes or less)

3. BRT OPERATIONS IN SELECTED DEVELOPING CITIES

BRT has undoubtedly improved the quality of public transportation in several Latin American cities and in recent times in Asian cities. Indeed, Latin American cities of Curitiba and Bogota have become important reference models for public transportation because of the BRT networks successfully implemented in these cities. Some of the examples of successful BRT operations in developing cities are presented in the following sections:

Curitiba

Curitiba is considered one of the first cities to have implemented a BRT system. It pioneered BRT in Latin America and has been a key inspiration for other cities on the continent, including Bogota (Duarte Carvajal, 2009; Ardila, 2004). In 1974, it introduced the exclusive bus lanes for the first time and changed the routing structure from point to point bus routing to a trunk and feeder system, called 'express' routes. Then, it introduced special, larger capacity buses that operated only on the trunk corridors. It was in 1990, that the current system, where the entire stations are closed to allow free transfers, and the pre-paid boarding tubes were also developed (Ardila, 2004).

Bogota (TransMilenio)

Serving the city of Bogotá, Colombia, TransMilenio is one of the world's premier Bus Rapid Transit (BRT) systems. In January 2006, the system carried over one million passengers per day on a network of high capacity trunk corridors, supported by feeder services that extend system coverage to peripheral areas of the city. TransMilenio is also the centerpiece of a long-term urban renewal and mobility strategy that prioritizes walking and cycling and discourages private vehicle use. The trunk and feeder system in the first phase of TransMilenio, consisting of three corridors, allowed the number of buses operating in the corridor to be reduced dramatically, from 650 buses/hour direction on heaviest link, down to about 270. Because the buses were much larger and speeds much faster, the system's total capacity is probably above 45,000 pphpd. Operating speeds at the time averaged 18kmph, but often were much lower, whereas after the reforms average speeds rose to 26kmph (Hook, 2005).

Guangzhou (GZ BRT)

The first phase of the Guangzhou Bus Rapid Transit (GZ BRT) opened in February of 2010. Before GZ BRT, Zhongshan Avenue's traffic speeds were plummeting and hundreds of buses blocked traffic while struggling to pick up passengers. Today, travel speeds are up 29% for buses and 20% for mixed traffic. After less than a year of operation, overall bus ridership in the corridor was up 18% over the year before and GZ BRT was averaging 805,000 total daily trips on the thirty-plus routes which use all or part of its 22.5-kilometer corridor of fully-segregated rapid bus lanes. At peak hour in the peak direction, GZ BRT carries 27,000 people—more than any metro line in mainland China except Beijing's Lines 1 and 2 (Hughes and Zhu, 2011).

Jakarta (TransJakarta)

TransJakarta was the first BRT system in Southern and Southeast Asia. . In 2004, the Trans Jakarta bus way was started along a 12.9 km corridor through the city centre. In 2011 TransJakarta carried around 115 million passengers (about 310,000 passengers per day) which was an increase of 32% the 87 million passengers carried during 2010. Currently it has the world's longest BRT routes and has more than 520 buses in operation. Nevertheless, demand on TransJakarta has been higher than projected, at roughly 50,000 passengers/day, or around 4,000 pphpd (TransJakarta, 2004). Trans-Jakarta is attracting some 15% of passengers from private motor vehicles and from competing bus routes.

Figure 2: Transjakarta (Indonesia)

Delhi BRT

In India, the first phase of BRT system has been implemented in Delhi (Mohan, 2009; TRIPP, 2005). The bus corridor has improved the mobility of the people and the bus speeds around 18 kmph, 150% faster than buses outside the corridor (12 kmph). The traffic volume on the corridor is high with more than 1, 35,000 vehicles are daily registered on this corridor (in 16 hours). Between 35-40% of these vehicles are cars; however, they carry only 15-20% of the total commuters. On the contrary, buses, which accounts only for 2-2.5%, carry around 55-60% of the same. The rest of transport is comprised by NMT; two-wheelers or rickshaws. As more bus users have increased, the overall reduction in travel time along the corridor for all users is estimated as 19%. In addition, the segregation of bicycles and pedestrians has improved the travel experience and the perception of safety (DIMTS, 2010; Hidalgo, 2009; RITES, 2011; Tiwari, 2009).

Furthermore, BRT corridors were installed in Seoul as a part of reform of its public transportation and first stage commercial operation of BRT was also started in Beijing (Matsumoto, 2006). Indeed, BRT is growing in popularity because it can be cost-effective and it works (Levinson et. al., 2003).

4. DHAKA'S EXISTING TRAVEL CHARACTERISTICS

The latest BRT study estimated that on an average day 21 million trips are taking place in Dhaka metropolitan area (ALG, 2011). Despite the rapid growth of motorised traffic in Dhaka, non-motorised transport still remains the dominant mode for the city dwellers who are mostly middle and low income groups. More than 40% of the city trips (see Table 1) are served by walking and rickshaw (DHUTS, 2010). The varied traffic mix and heavy concentration of non-motorised vehicles with almost 70% of the available road space is occupied by rickshaws and their dominance is expected continue in the foreseeable future (Hoque and Hossain, 2004). Currently, rickshaw movements are however restricted in some major roads.

Table 1: Modal share in metro Dhaka

Mode	**Percentage of Share**				
	DITS *(1994)*	DUTP *(1997)*	JBIC Study *(1999)*	STP *(2005)*	JICA Study *(2009)*
Walk	60.1	62.82	62.05	14.0	19.09
Rickshaw	20.1	20.04	13.28	34.0	38.19
Bus	12.8*	10.42*	10.22	44.0*	29.83
Auto-rickshaw			5.83		5.73
Passenger Car	7.0**	6.72**	3.97	8.0**	4.30
Others			4.65		2.86
Total	100	100	100	100	100

* Transit
** Motorized (Non Transit)

The modal distribution by income groups is shown in Table 2. It shows that trips on foot is made by the low income group (73%) while most of the rickshaw trips are made by the middle income group (59%) (DHUTS, 2010). The significance of walk and rickshaw trips is clearly evident as they relate to 97% of the city dwellers.

Table 2: Modal share of trips with respect to income groups

Income Group	Proportion of Income Groups (%)	Modal Share			
		Walk	Rickshaw	Transit	Motorised (non-transit)
Low (<12500)	48	73	38	41	14
Medium (12500-55000)	49	26	59	56	66
High	3	1	3	3	20
Total	**100**	**100**	**100**	**100**	**100**

Source: Final Report, Dhaka Urban Transport Network development Study, 2010

Around 30% of the total travels are attributed to bus trips (ALG, 2012). Buses comprise only 9.7% of the vehicle mix that combines all vehicles and pedestrians, but bus passengers account for 77% of all public transport users. However, Dhaka is perhaps the only city of its size without a well-organised, properly scheduled bus system or any type of mass rapid transit system. The city is experiencing marked growth in private transportation, and public transportation is highly disorganised and inefficient and operated by a myriad of bus and minibus companies. According to Bhuiyan (2007), more than 5,500 buses and minibuses are operating in the city. Figure 3 depicts the glimpse of the prevailing traffic congestion situation in Dhaka. Much is needed to be done to serve existing transport needs better. The challenge is to establish an overall framework for a multi-modal transport system that effectively serves current and future land uses and satisfies demand to the greatest extent possible.

Figure 3: Traffic congestion in metro Dhaka

5. BRT IN METRO DHAKA

In the context of present challenges of increasing severe traffic congestion and sustained growth of personalized car ownership, revitalization of public transport is a core issue and improving the quality of public transport, increasing public transport capacity and thus relieving traffic congestion are urgent matters. There are several options in addressing mass transit facilities like Bus way/ BRT, Tram, LRT (Light Rail Transit) and Metros (Hoque and Hossain, 2004*)*. With relative advantages, BRT option is seen as an urgent consideration for Dhaka (Hoque et. al. 2012). The context and the expected benefits of introducing the proposed BRT corridors in Dhaka are briefly discussed.

5.1 The Context

In response to the transport challenges, public transport in particular, the Strategic Transport Plan (STP) for Metro Dhaka recommended a package of comprehensive programs for the development of transport infrastructure over 20 year period (STP, 2005). Of most significant of the programs were three Bus Rapid Transit (BRT) routes within the development of six major corridors as mass transit routes as a means for achieving sustainable urban transport in the city. Three radial corridors as follows are thought to be potentially suitable for Bus Rapid Transit (BRT) introduction (see Figure 1).

- **Corridor A:** Starting in Uttara in the north and following Dhaka Mymensing Road, Pragati Road, DIT Road Toyenbee Circular Road to Saidabad Bus Terminal.
- **Corridor B:** Starting at Gabtalli and following Mirpur Road, Zahir Raihan Sharani Road to Saidabad Bus Terminal.
- **Corridor C:** Starting at International Airport following Airport Road, Shaheed Tazuddin Road and ending in Ramna area.

These three BRT corridors are now actively been considered by the government with the support from the development partners such as the World Bank and the Asian Development Bank. Currently, the authorities have taken the initiatives of implementing 2 segments of BRT line 3 comprising of (i) Gazipur to Airport Railway Station and (ii) Airport Railway Station to Keraniganj. The authors have been playing important role in developing the preliminary design phase of around 22 km length BRT route of Airport Railway Station to Keraniganj. Most of the BRT segemt will go at grade. However, some parts of the alignment will be elevated in order to segregate it from the mixed traffic lanes, avoid pedestrian crossings and reduce number of road intersections. Anyhow, BRT will operate on specially designed infrastructure and is planned to replace the current inefficient unpredictable bus transport services on the corridor and will always go segregated from mixed traffic lanes (ALG, 2012 b). A brief summary of the expected benefits and effects of BRT system is given in the following section. More details can be seen in Hoque et. al. 2012.

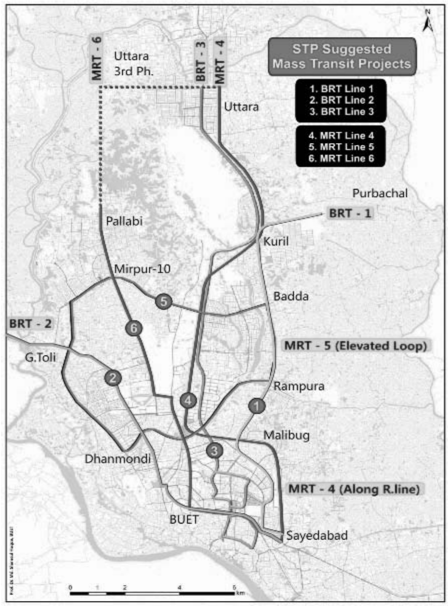

Figure 4: BRT and MRT Corridors proposed by STP

5.2 Expected Benefits of BRT in Dhaka

A key objective of the proposed BRT system is aimed at the reduction of congestion and travel time with emphasis on improved quality of public transit services. Essentially the implementation of the BRT system is expected to achieve (ALG, 2012 b): (i) Improve Public Transport Efficiency and (ii) Increase Public Transport Capacity. Some of the likely improvements and consequences of the implementation of BRT and its integration with other modes towards achieving the enhanced quality and sustainability of public transport services are (ALG, 2011):

(i) Improved Travel Performance: Decrease bus and general purpose traffic journey times in the corridor and improved connectivity.
(ii) Improvements in attractiveness of public transport: Promotion of service that attracts new users and patronage from other modes.
(iii) Congestion reduction: Shifts in market to public transport; Improvements in traffic behavior; traffic management and effective enforcement techniques.

(iv) Supporting special needs groups: Overall increases in mobility and specific improvements in availability and quality of mobility for the urban poor, elderly, handicapped and women in general.
(v) Industry support: Provide opportunities for effective private sector participation.
Keeping costs reasonable: A relatively low-cost of implementation sensitive to the local needs of Dhaka.
(vi) Effective regulation: To develop an effective and accountable system of regulation to select BRT operators and good governance standards.
(vii) Enhancement of management: To build capacity and develop an improved public transport management regime through new institutional and organizational frameworks to manage the corridor transport systems.
(viii) System integration: To better synchronize public transport systems with road and infrastructure development.
(ix) Safety enhancement: An overall increase in safety in the corridor through the design of system elements and enforcement approaches that promote safety including application of a safety audit.
(x) Pollution reduction: To reduce environmental pollution and ensure World Bank's social and environmental safeguard policies not only in construction period but also when the BRT is in full operation.
(xii) Enhancement of facilities for pedestrians: Provide and integration of pedestrian sidewalks and overbridges/crossings throughout the corridor, for public access in general.
(xiii) Urban environmental management/ Landscape Planning: Integrate transport more effectively with land uses and to improve the urban environment and increased accessibility to public transport along BRT corridors.

6. CONCLUDING COMMENTS

BRT is a cost-effective mode of transportation and is gaining its increasing popularity worldwide. It has emerged as an economical transit alternative for developing countries and its introduction has recently accelerated in Asia. The concepts, operating advantages and successful operations of BRT system are briefly reviewed in this paper. The relevance and the potential of introducing BRT system towards improved and enhanced quality of public transport services in metro Dhaka are discussed.

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Innovative Transit Systems and Practices – Relevant Programs under the Federal Transit Administration

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Abstract

The Office of Research, Demonstration and Innovation of the Federal Transit Administration (FTA) under the U.S. Department of Transportation funds and manages an array of transit related innovative research, development, and demonstration projects. It also encourages and identifies innovative transit practices and provides guidance in making good business decisions about transit technology and capital and operating investments involving the transit industry.

Recent programs and projects largely funded by the FTA involve an emphasis on improving the effectiveness of public transit operations, reducing energy and greenhouse gas emissions, and encouraging sustainability. These programs include Transit Investments for Greenhouse Gas and Energy Reduction (TIGGER), the National Fuel Cell Bus Program (NFCBP), and Intelligent Transportation Systems (ITS). Under these activities, the FTA provides funding for research, development, demonstrations, evaluations, and standards involving advanced transit technologies all leading towards operations and deployments in public transportation systems that are safer, more efficient, and more environmentally conscious than before.

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Introduction

The Federal Transit Administration (FTA) is one of thirteen Modal Administrations within the U.S. Department of Transportation (DOT). The FTA establishes national policy with regard to public transit operations, provides planning and research assistance, provides capital and operating funds to help ensure the safety and quality of existing and new public transit systems, and supports and encourages the deployment of innovative practices meeting DOT's overall strategic goals. These goals include enhancing safety, reducing congestion, increasing global connectivity, promoting environmental stewardship, and helping to insure proper security, preparedness and response involving the overall transportation systems in our country. The FTA manages over $10 billion per year in (US DOT, 2011) federal funding dedicated to improving and refurbishing existing transit systems, and constructing new transit systems in order to meet the needs of transporting people nationwide while remaining cost efficient and environmentally friendly mass transit.

The Office of Research, Demonstration and Innovation within the FTA establishes research initiatives (FTA.gov, 2011) and provides guidance in making good business decisions in deploying transit technology, and in improvements involving operational and capital investments for the transit industry. It provides grants and cooperative agreements to research organizations, transit authorities, and non-profit institutions across the country to identify best practices and make them available, particularly in assisting to direct future transit investments, and to identify future transit industry research needs. Grants and cooperative agreements are also provided to conduct research, development, demonstrations, evaluations, and to develop standards. FTA's research program is driven by a Strategic Research Plan, which focuses on five goals. These are to provide transit research leadership, increase transit ridership, improve capital and operating efficiencies, improve safety and emergency preparedness, and protect the environment and promote energy independence.

This paper will discuss a host of innovative systems and practices developed and established through the programs managed by the FTA's Office of Research, Demonstration and Innovation.

TIGGER Program

The FTA implemented the Transit Investment for Greenhouse Gas and Energy Reduction (TIGGER) Program in 2009 under the American Recovery and Reinvestment Act (ARRA). The Program allocates funds for capital projects that reduce greenhouse gas emissions or lower the energy use of public transportation systems. Capital projects under the Program have been competitively selected through a Request for Proposals to the transit industry. This program provided $100 million to public transit authorities in the federal Fiscal Year (FY) 2009. Over 500 proposals were submitted in that FY from transit agencies across the nation representing nearly $2 billion in proposed project funds. In the following year, Congress authorized an additional $75 million for the Program through the Transportation, Housing, and Urban Development, and Related Agencies Appropriations Act of 2010. The TIGGER Program was funded again by Congress in the amount of $50 million in FY 2011 through the Department of Defense and Full-Year Continuing Appropriations Act.

Selected projects funded under the TIGGER Program include renewable energy production using solar and wind technology; wayside and on-board energy storage for rail systems; advanced hybrid electric, fuel cell, and all battery electric buses; and the implementation of intelligent transportation systems (ITS). These projects all enhance operational efficiencies, demonstrate innovative technology concepts, and reduce energy or greenhouse gases in an operational environment. The projects are divided into three main categories: Bus Efficiency, Rail, and Facility Efficiency.

Technology	Sub-Category	Number of Projects
Bus Efficiency	Hybrid Buses	19
	Efficiency Retrofit	5
	Zero-Emission Buses	16
	Total Bus Efficiency Projects	**40**
Rail	Wayside Energy Storage System	3
	Locomotive Upgrades	3
	On-Board Energy Storage	2
	Controls	2
	Total Rail Projects	**10**
Facility Efficiency	Facility Upgrades	13
	Solar	15
	Wind	2
	Stationary Fuel Cell	3
	Geothermal	5
	Total Facility Efficiency Projects	**38**

Figure 1 – Summary of Projects by Technology Category

Among the three main categories, almost half of the TIGGER projects (40 out of a total of 86 projects) are Bus Efficiency related, including purchase of new advanced buses with hybrid-electric or zero-emission propulsion systems (all battery or fuel cells), and the retrofit of existing buses to increase efficiency. One of the fuel cell technology projects involves the construction of a hydrogen charging station for an existing fleet of fuel cell buses. The hydrogen for the station is produced through electrolysis using electricity generated by solar panels installed on a bus maintenance facility. Two projects involve the latest innovative, in-ground inductive charging system for all-electric buses. Several involve the installation of fast-charging infrastructures. Others include the retrofit of electric-powered systems into existing diesel buses. Several fuel cell bus projects funded by the TIGGER Program were made possible by developments resulting from the National Fuel Cell Bus Program, which will be discussed in the next section of this paper.

The successful introduction of inductive charging systems for batteries on buses is relatively new to the U.S. transit industry due to their expensive cost and relative complexity. With an induction coil contained in a charging base station and receiver coils compacted in a portable device mounted on the vehicle, the device on the vehicle converts the energy generated from the electric field created through induction into electrical current to charge the battery on board (Hadley, 2010). Inductive charging with charging base stations not only eases the construction of charging infrastructure, but also revolutionizes the typical charging mechanisms. By embedding the charging base stations into roadways, vehicles with the receiver devices mounted on them would be able to charge their batteries as they operate on the road. A study on inductive charging for electric buses by the Center for Energy, Transportation and the Environment at the University of Tennessee at Chattanooga, indicated that a charge time of one minute, operating distance of one mile per charge, cost of charge of eight cents per mile, and zero tail pipe emissions are possible (Bailey, 2012). Building on these concepts, one TIGGER project in Howard County, MD, involves the replacement of worn-out, diesel-on-chassis buses with all

Figure 2 – Bus Entering Wireless Charging Area

battery-electric buses, accompanied by an inductive, in-road charging system and associated infrastructure.

Unlike inductive charging, fast-charging uses conventional conduction between the vehicle and the charging station through electrical wire. Recent improvements in this technology have reduced the charging time significantly. The VIA Fast-Charge Electric Bus Project in San Antonio, Texas, will replace diesel buses with battery-electric buses and the installation of a quick-charge station that can fully charge the batteries in under ten minutes. This quick-charge station also uses solar photovoltaic (PV) panels to capture solar power for supplementary power usage at the charging station. In addition, VIA contracted with its local energy provider to use wind-generated electricity to power the electric buses. This project is a perfect example where agencies from different sectors are cooperating with each other to achieve environmental goals, demonstrating environment protection in a collaborative effort.

Unless diesel buses have reached the end of their useful service life in a typical transit authority operation, it is extremely uneconomical to replace existing fleets of diesel buses with new, more advanced vehicles. Yet, given today's political climate that encourages the use of sustainable and energy efficient systems and technologies it is hard to avoid subsystem retrofits in mid vehicle life that improve vehicle emissions and engine efficiency, especially in large urban areas. Researchers have developed electric-powered cooling systems to replace mechanically and/or hydraulically driven cooling systems in diesel buses. The Tri-County Metropolitan Transportation District of Oregon installed electric-powered cooling systems to several buses from its existing fleet. A high output alternator, a system of heat exchangers, and eight electronically controlled electric fans will replace the original bus alternator and cooling systems (EMP, 2010). This will improve the fuel efficiency of the transit buses, reduce emissions, and increase safety in maintenance by eliminating hydraulic fluids in the original system.

There are many more projects under the TIGGER Program funding. Though many of them are still in the process of project completion, the TIGGER Program proves to be promising in introducing innovative systems and new practices into existing transit systems while reducing greenhouse gases and energy.

National Fuel Cell Bus Program

The National Fuel Cell Bus Program (NFCBP) was established originally under Section 3045 of the Safe, Accountable, Flexible, and Efficient Transportation Equity Act: A Legacy for Users for 2005 (SAFETEA-LU). Under this Program, the FTA aims to accelerate the commercialization of fuel cell powered buses in this country.

The Program involves the research, development, demonstration and evaluation of fuel cell propulsion systems on a range of platforms and over a variety of climate and geographic conditions. The U.S. Congress has provided $75 million to date for Program activities, matched by an equal share of cash or in-kind contributions by local authorities, non-profit, and private companies.

The focus of the NFCBP has largely been on the development of full-size, heavy-duty fuel cell, and fuel cell electric powered transit buses. The NFCBP aims to achieve the following goals: facilitate the development of commercially viable fuel cell bus technologies; improve transit bus fuel efficiency and reduce petroleum consumption; reduce transit bus emissions; establish a globally competitive U.S. industry for fuel cell bus technologies; and increase public awareness and acceptance of fuel cell bus vehicles. The Program has a number of performance objectives to achieve its goals as summarized in Figure 2 below.

CURRENT PERFORMANCE OBJECTIVE	*POSSIBLE STATUS AT CONCLUSION OF NFCBP*
Less than 5x cost of conventional bus	*Less than $1.0M fuel cell bus achievable*
4 to 6 years or 20,000 to 30,000 ours of durability for the FCPS*	*Data indicates continued progress under current NFCBP portfolio well above 10,000 hours*
Double fuel economy compared to commercial transit bus	*Fuel efficiency continue to increase*
Bus performance equal to or greater than equivalent commercial bus	*Bus performance exceeding current diesel buses in terms of acceleration, and braking with continued improvements over current FCB in availability and reliability*
Exceed current emissions standard	*Exceeds – zero emissions; emissions attributable to H_2 generation improving*
Foster economic competitiveness in fuel cell bus technologies	*Multiple manufacturers and platforms demonstrating buses, with Buy American compliance possible*
Increase public acceptance for fuel cell bus technologies	*Continued progress as more buses are deployed, leading to a small fleet deployments*

*Original program solicitation called for 10,000 to 20,000 hours

Figure 3 – Summary of Program Targets

The NFCBP's portfolio of projects was selected competitively under a Request for Proposals. Each project was awarded to one of three non-profit organizations. These include the Center for Transportation and the Environment in Atlanta, GA; the Northeast Advanced Vehicle Consortium in Boston, MA; and CALSTART in

Glendale, CA. The role of these non-profits is to coordinate among the various manufacturers, transit authorities and subsystem suppliers and integrators involved in selected projects to ensure adequate scopes of work are developed and proper project management and oversight is provided.

The current portfolio includes 20 projects involving the development and demonstration of 16 fuel cell buses operating in 11 locations across the country. Although every project under this portfolio is important, three specific projects stand out and are worthy of mention.

One project involves the Connecticut Transit (CTTRANSIT) operating in Hartford, CT. This agency started its efforts to demonstrate the feasibility of fuel cell buses in April of 2007, collecting data on bus operations and performance and on the efficiency, reliability, and durability of its fuel cell system (Eudy, 2011). CTTRANSIT is currently implementing the "Nutmeg Fuel Cell Bus Project" to test a fleet of newly developed fuel cell dominant hybrid fuel cell buses in revenue service. The bus under this project has achieved significant reductions in weight and higher top speeds than previously tested buses. This project is completed with data collection in July of 2011 and in the process of preparing the first results report with service evaluation.

One other NFCBP project of note involves AC Transit, located in Oakland, CA. Under this effort, a fleet of 12 fuel cell buses is currently operating in the San Francisco Bay Area. This project focuses on collecting bus reliability data and is investigating the future cost reduction potential and requirements for larger fleets of fuel cell buses in the future (Eudy, 2010). Developed under a similar scope and specification as the Nutmeg Fuel Cell Bus Project, the new buses in this project have achieved significant reductions in weight and higher top speeds than previously developed buses. An initial first evaluation has been completed for the past 5-year period, and final results have been published in August of 2011. These results indicate that the average hydrogen fuel economy is 52% higher than similar diesel buses, averaging about 6.05 miles per diesel gallon equivalent (mpDGE) compared to only 3.99 miles per gallon (mpg) for diesel buses (Chandler, 2011). A second evaluation is expected to be conducted in early 2012.

Another significant effort is "The American Fuel Cell Bus Project" led by CALSTART. This project focuses on the development of a bus that meets Buy America requirements for the manufacture and assembly of all major components, including the bus body, fuel cell, and other major subsystems. Owing to the difficulty of finding project partners under the NFCBP that meet "Buy America", particularly with regard to the fuel cell subsystem, the Program received a "Buy America" Waiver from the beginning. However, it was felt that an All-America compliant fuel cell bus would send a positive signal to the U.S. manufacturing base that the development of such a bus was indeed possible. This would help in the policy goal of establishing a globally competitive U.S. industry for fuel cell bus technologies. The project involves the integration and assembly of an El Dorado bus body (made in Riverside, CA) with a domestically produced Ballard fuel cell system. Demonstration and testing was initiated in late 2011. Early data results are promising in speeding commercialization of fuel cell buses in compliance with "Buy America". The El Dorado hydrogen fuel cell bus is averaging 6.98 mpDGE compared to 3.4 mpDGE for compressed natural gas (CNG) buses (Eudy, 2011).

Intelligent Transportation Systems for Transit

The Intelligent Transportation Systems (ITS) Program is a joint effort involving a number of different modes (including the Federal Highway Administration, the Federal Transit Administration, the Federal Railroad Administration, and the National Highway Traffic Safety Administration) in the U.S. DOT to conduct research and development on promising ITS technology in order to improve the safety and efficiency of the transportation system in our country. Led by the Research and Innovative Technology Administration's (RITA) Joint Program Office (JPO), the ITS Program involves electronic and information technology applications to advance safety, mobility, and environmental sustainability. This Program places emphasis on the integration of intelligent vehicles and intelligent infrastructures and on interoperability of technology to improve the nation's transportation system and infrastructure (ITSJPO, 2011). The FTA is significantly involved in several ITS Program initiatives, including the Vehicle Assist and Automation Program, the Integrated Corridor Management Program, and the Connected Vehicle Program.

Vehicle Assist and Automation

Vehicle Assist and Automation (VAA) technology on buses enables precise and safe operations on extremely narrow lanes and at bus stations and maintenance facilities. Such technology can include optical, magnetic, or Global Positioning System (GPS) hardware on a vehicle that is integrated with baseline infrastructure coordinates. Use of this technology can provide partial or full warning and/or control to a driver and/or vehicle subsystem. VAA technologies can provide a number of benefits to transit agencies for more efficient and safe operations, such as improved trip times, quicker and easier boarding by passengers at bus stops and stations through precision docking, and reduced likelihood of accidents during operations (in normal and narrow travel lanes). VAA enabled operations also have the potential for a reduction in right-of-way requirements (Hardy, 2005). Potential future applications of VAA technologies include vehicle platooning (two or more vehicles in an operational consist) and fully automated, driver-assisted operations.

The FTA and the JPO have funded several VAA demonstration projects involving transit revenue services under different operating environments, including extreme weather conditions, in order to validate the benefits and feasibility of VAA technology. The overarching objective of the demonstrations is to facilitate the implementation of innovative strategies incorporating ITS in vehicle guidance, particularly in exhibiting measurable travel time savings through a reduction in vehicle run times; a decrease in operating costs; an increase in ridership levels; and a decrease in long-term traffic congestion. The FTA and JPO funded efforts include demonstration projects on implementing magnetic marker sensing and inertial navigation system (INS) on buses for lateral guidance on a HOV lane and through a toll booth and precision docking in Oakland, CA; using a magnetic marker sensing system on buses for precision docking and lane keeping in Eugene, OR; and using optical and radar based sensors on buses for lateral guidance on the inside shoulder of I-805 in San Diego, CA.

A successful VAA demonstration effort not involving direct FTA assistance was the Driver Assist System (DAS) project developed by the University of Minnesota and implemented by the Minnesota Valley Transit Authority. This project involved the operation of 10 buses using GPS-based VAA technology in rush hour traffic along 20 miles on the shoulder of TH77, TR62, and I-35W in Minneapolis, MN (Pessaro, 2011). According to a study on bus-on-shoulder operations by Craig Shankwitz of the University of Minnesota, removing 12 vehicles on a road and substituting buses on the roadway shoulder at traffic service level “F” can improve traffic flow up to level “E” (Shankwitz, 2011). This study indicates the benefit of using bus-on-shoulder as an operational strategy. Yet, due to the narrow shoulders (10 foot wide lane vs. 12 foot wide lane), bus operators often hesitate to deploy such options without technology assistance in order to maintain operational safety. Differential global positioning system (DGPS) technology has allowed the transit authority to operate on-shoulder with lane position feedback to the driver through a heads-up display, virtual mirror, vibrating seat, and actuated steering. This has improved the safety of the vehicles operating on-shoulder and increased drivers’ confidence when driving on-shoulder.

Integrated Corridor Management

The Integrated Corridor Management (ICM) Initiative is another one of the multi-year U.S. DOT ITS efforts involving the FTA, Federal Highway Administration (FHWA), and RITA. It involves the development and demonstration of the dynamic transportation system management of a multimodal corridor as one system instead of the current style of separated management. Though individual facilities continue to be operated by local agencies, operational strategies, such as modal shift, incident response, and signal management, are integrated to improve overall corridor performance. With this integrated system, transportation corridors are able to incorporate combined ITS technologies to reduce congestion and enable travelers to make alternative transportation options based on accurate and real-time information on traffic conditions. The transportation system, as a whole, then becomes more cost and energy efficient.

The ICM effort involves four elements in order to "promote innovation in the development of new approaches for efficiently managing assets within a corridor". These include foundational research; corridor tools, strategies and integration; corridor site development, analysis and demonstration; and ICM outreach and knowledge and technology transfer (ITS.gov). The U.S. DOT has chosen Dallas, TX and San Diego, CA as pioneer sites that involve significant transit ITS deployments for further validating and deploying the concepts and benefits of ICM, such as improving situational awareness, enhancing response and control, better informing travelers, and improving corridor performance.

	Corridor Assets to Be Integrated with ICM									
	Freeway			Arterial	Bus			Rail		
Pioneer Site Location	HOV	Tolling	Value Pricing	Real-Time Control	Fixed Route	Express Buses	Bus Rapid Transit	Commuter Rail	Light Rail	Subway/Heavy Rail
Dallas, Texas	◆	◆		◆	◆	◆			◆	
Houston, Texas	◆	◆	◆	◆	◆	◆	◆			
Minneapolis, Minnesota	◆	◆	◆	◆	◆	◆	◆			
Montgomery County, Maryland	◆			◆	◆	◆		◆		◆
Oakland, California	◆	◆		◆	◆	◆	◆	◆		◆
San Antonio, Texas				◆	◆	◆				
San Diego, California	◆	◆	◆	◆	◆	◆	◆			
Seattle, Washington	◆			◆	◆	◆		◆	◆	

Figure 4 – ICM Pioneer Site Location and Corridor Assets

The Dallas ICM site is integrating the regional systems and operations along the US-75 corridor, led by the Dallas Area Rapid Transit (DART) Authority. This freeway network will include a management center, CCTV cameras on the freeway, detection systems, dynamic message signs with real-time travel information, and mobility assistance patrol, while the arterial network will deploy connection among traffic signals with 911 integration, surveillance cameras, arterial dynamic message signs, and traffic signal priority. With the integration of such technologies and transportation systems in the region, the Dallas site is expected to provide improved reliable real-time travel information, increased traffic flow in the corridor, expedited emergency responses, and improved intermodal travel decisions.

Connected Vehicle Program

The Connected Vehicle program is the largest effort under the ITS Program within the U.S. DOT. The Connected Vehicle program is led by RITA's JPO and is a cross-modal initiative involving the FHWA, FTA, Federal Motor Carrier Safety Administration (FMCSA), Federal Railroad Administration (FRA), and the National Highway Traffic Safety Administration (NHTSA). Based on the potential of wireless technologies to improve the safety, mobility, and environmental impacts of existing transportation systems, the Connected Vehicle program aims to "create safe, interoperable connectivity between vehicles, infrastructure and mobile devices" that can address real-world transportation problems (RITA, 2009).

Because of the wide applicability of the Connected Vehicle program, it has been divided into several categories to focus and prioritize funding and research efforts more effectively, including the improvement of technology; the development and testing of applications using technology; and the review and identification of technology policy and institutional issues.

The basis of the Connected Vehicle program is early ITS research efforts in dedicated short range communication (DSRC) technology, allowing wireless communication of real-time information between devices mounted on vehicles and the transportation infrastructure. The joint efforts of all modal administrations within the U.S. DOT are focused on this technology enabling travelers and transportation managers to access and provide roadway information in real-time; and providing applications to assist decision-making depending on roadway conditions and hazards to improve safety and mitigating traffic to reduce congestion; and promoting reliable and effective travel alternatives to decrease environmental impacts. Overall, the Connected Vehicle applications research focuses on enhancing safety, mobility, and the environment.

Safety applications are the major priority of the Connected Vehicle research effort, which divide into two main categories: Vehicle-to-Vehicle (V2V) Communication for Safety, and Vehicle-to-Infrastructure (V2I) Communication for Safety. The mobility applications are a second priority within the program effort, including Real-Time

Data Capture, and Management and Dynamic Mobility Applications. And finally, the environmental applications consist of Application for the Environment: Real-Time Information Synthesis (AERIS) and Road Weather Connected Vehicle Applications.

Transit applications under the Connected Vehicle Program include, but not limited to: DSRC-based V2V and V2I safety applications for transit vehicles; utilizing real-time information and data captured for situational safety, environmental conditions, congestion data, and cost information regarding transit operation from different elements within the transportation system under; implementing Signal Phase and Timing (SPaT) and geospatial information map technology to increase intersection safety and efficiency for transit operations; and the development of Multimodal Integrated Payment Systems which includes transit bus services.

Conclusion

The FTA manages and oversees a number of innovative programs and projects involving the research, development, and deployment of various transit systems and their associated operations. These include the TIGGER program, the National Fuel Cell Bus program, the Vehicle Assist and Automation project, the Integrated Corridor Management initiative, and the transit element of the Connected Vehicle program. Each of these programs and projects contributes to the effort to improve the overall transportation system of our country by ensuring safety, quality, and effectiveness of public transit during operations; by encouraging innovation in the operation, purchase and construction of transit capital; and by providing monetary and policy support for the implementation of innovative practices to transit agencies. The overarching goal of the FTA is to enable safe, environmentally sustainable, cost efficient, and socially acceptable mass transportation systems and operations in communities across the nation. Transportation affects everyone on a daily basis. The FTA's role is to ensure that the mass transit contribution to the overall transportation picture is a sound and effective one.

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Infrastructure Investment Decision Making: The Emerging Roles of Planning and Sustainability

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Abstract

Since September 11, 2001, New York City has been proposing, planning and building more than $30 Billion of transport infrastructure. Projects that went through the MPO LRP and TIP processes have been started; however, the 2013 concerns of sustainability and resilience had not been taken into account. Further these projects – some near or post completion has had severe cost over- runs, disrupting the long term capital program. What has driven these projects to completion and what is “left on the table”? This paper will examine factors that have raised questions about the integrity of the traditional transportation planning process, and the future of transportation planning bounded by significant environmental constraints.

Introduction. New York City, as do all urban areas, follows the mandated joint planning regulations of USDOT, and presents its plans and projects through the vetting of the regional MPO. In fact, urban areas in the US have done so since the mid 1970s, when planning was directed towards increasing, significantly, highways and transit capacity. The outgrowth, well documented in many books and papers has been the inability of States and local areas to keep up with both capacity demands and State of Good repair (low ASCE Infrastructure Scorecards). In addition, since the introduction of ISTEA in 1991, States and local areas have been trying to accommodate transportation planning to meet environmental (and, in particular Clean Air) standards. The purpose of this paper is not to review these issues so well discussed elsewhere, but to recognize them as background for the inability of local planning in the Greater New York Region to address and keep pace with emerging transportation needs as well as significant population shifts. Part 1 of the paper addresses these issues. Part two of the paper addresses the emerging demands made by the impacts of the environment – namely energy and global warming, and the huge culture shifts brought about by the very rapid adoption of new technologies, especially IT and smart devices. The paper concludes by recommending new approaches to transportation and infrastructure planning.

Part 1. The costs of the current planning process. The trauma of September 11, 2001 made all in New York City and the Region – transportation professional and citizen alike – aware of how critical, yet how fragile the systems of transport, public, roads, water networks were. All of lower Manhattan was closed off in the months following 9.11. Over 100,000 jobs were dislocated; over 80,000 transit trips per day to just a handful of damaged rail stations had to be served. With Federal money promised for

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the damaged stations, the planning community as well as urban leadership demanded that vigorous attention to rebuilding as well as renewing and expanding the transit system and street flow in lower Manhattan.[i] Against this background City, State and Regional agencies proposed more than $30 billion of transportation projects; some were in the Lower Manhattan area, but many were serving other parts of the region. With a slight downward shift in the regional economy due to 9.11, political leaders looked at reestablishing a renewed transportation base that would be key to recapturing the decade of economic growth just seen. [ii]

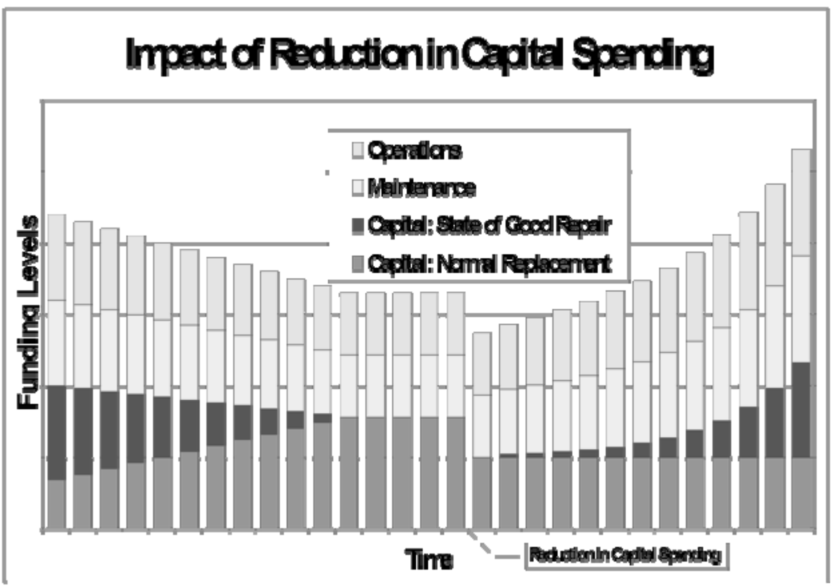
$30 billion of new or renewal projects were too many to digest by the agencies, even by New York standards. To realize the capital needed for more than a dozen proposed projects bonds would have to be issued, subsidies acquired and fares and tolls increased. The Partnership for the City of New York (PCNY) approached the author and his group and requested that a cost benefit analysis be carried out, helping this influential business group set priorities in project selection. This was done and discussed in the literature.[iii] While public discussion was still taking place, the Metropolitan Transportation Authority (MTA) was planning and starting to implement four large mega projects from this list totaling $22.4 billion (estimated). Today (June 2013) most of these projects have been started, but all have been delayed and one has to be rebuilt. The most critical projects are:

- Second Avenue Subway – only the first of three phases is being built; budget $4.5B, completion date 2016 – over budget (Full Funding Agreement $4.05B) and late
- East Side Access (LIRR into Grand Central Terminal) – Original Budget $6.4B,Current Estimate $8.2B – completion 2019
- South Ferry Subway station – rebuilt after Sept 11 to new standards, but totally submerged in Hurricane Sandy and to be rebuilt again at a cost of greater than $600m, more than the original cost.

The first two projects are illustrative of how planning and budgeting have lost accuracy; the third illustrates the impacts of extreme events and forces a discussion of the now demanded resiliency planning.

Much has been written about the growing lack of integrity of the traditional transportation planning process.[iv]These projects – subject to the MPO process – did not go through many steps of the traditional, rational planning process. Each of these projects had been proposed and studied as a stand - alone project, but there may be regional impacts that suggest combinations of projects, or carrying out projects with associated smaller scale, but important street improvements, ITS additions or even changes in regulations and transportation laws would have been appropriate. And none discussed the impacts of Capital budgeting on operating costs and State of Good repair. Figure 1 below, illustrates this impact.

Capital budgeting for transit has taken an urgent position in New York regional planning. No major projects had been built since the mid-1900s; yet the City is in the midst of great economic expansion and population growth. High property values in Manhattan have moved moderate income housing to the outer boroughs and neighboring states, necessitating improved transit access. But general funding for the MTA has been relatively stable, not increasing , and every capital or operating dollar is hard fought over. This has taken a toll on operating revenue as station improvements have been slowed, modernization – so necessary for global competition has been slowed and fare systems not yet ready to take advantage of paying by smart devices. With the mandated planning process so well thought out and institutionalized, what have been the factors leading to the inability to build much needed capacity and capacity improvements in the New York Region.



Some of the factors observed in our BCA for the NYC Partnership included:

1. All of the initial project estimates were substantially lower than the estimated final costs. Original estimates, often hastily done, ignoring risk and politically competitive were made to secure placeholders for Federal funds. However, no true cost estimate can be done until the full engineering plans and site costs have been evaluated. Quest for the Federal dollar has been a strong factor in project choice and priority. In the New York Region, the large agencies, MTA and NY State DOT play large roles at the MPO table. However, as they provide low estimates of capital projects – to allow for a broader distribution of projects, later true costs actually reduces the dollars available for a given project – causing delay, and, perhaps pushing smaller projects off the table or

far into the future. The MTA Station Modernization program has been a victim of capital budget reassessment.

2. Flaws of first funding estimates. None of the projects noted in the PCNY study had accurate first cost estimates. The table below shows a consistency within MTA estimates of greatly underestimating both costs and time to completion. This is seen in Table 1 where for these 4 projects alone the total cost has escalated to $4 billion.

Table 1. MTA Expansion Projects (Source MTA)

Project	Years delay	Cost esc. $B
East Side Access	6	2.9
2nd Avenue Subway – Phase 1	3	0.5
Fulton St transit terminal	4	0.5

3. The MTA Capital program is under funded – and competition for funds for these expansion projects comes from modernization projects, State of Good Repair and the high costs of fleet replacement.
4. The traditional means of paying for capital projects – subsidies based on tax revenues and debt issuance are inadequate to meet these project needs and there must be a political solution to finding new sources of revenue. This has been exacerbated by the financial meltdown of 2008. The will to find new revenue bases[v] in a time of fiscal austerity has been nearly nonexistent.
5. One project, added to the PCNY list came from the City of NY and was not on an original, MPO vetted LRP; this is the extension of the 7 line subway (Times Square to Flushing Queens) west to 11th Avenue to stimulate development of far west side Manhattan property. The project estimate was $2B, final cost will be $3B. The fundamental question asked addresses the relevancy of the planning process when favorite political projects are added (and use real capital dollars); are they – in the long run – as valuable and cost effective as planning process vetted projects.

Will projects be abandoned or delayed or substantially down sized? Is there a strategic process to evaluate where the next dollar should be spent, or how the next dollar should be raised. In the next section the author will discuss lessons learned from the PCNY study. These lessons directly address the importance of strategic approaches

Lessons learned from the PCNY study. The PCNY study examined 12 candidate projects. Each had a defined – first estimate - budget, which we were directed to use. As mentioned a number of project were initiated by the MTA, some by the City of New York, some by the Port Authority of NY&NJ. All project first estimates were low. There were no final engineering design estimates done, nor estimates refined by project managers. And, based on data supplied, transportation benefits for these transportation projects were not adequate to justify the costs; additional benefits, economic development, were necessary to show a B/C >1. Perhaps there is no greater flaw in mega project planning than the misrepresentation of total project costs. Project capital budgets are finite; projects in NYC have been selected on a competitive basis. This competition is not an all projects going through exhaustive BCA, but based on advocacy and the availability of project specific federal funds.

Our study identified the following constraints that mitigate against true project planning and evaluation:

- The availability of funding, its source (Federal grant or local subsidy and debt issuance) and limitations
- The boundaries established by strong public agencies – they acted independently, as is their mission, addressing first their own long term needs and avoiding a system perspective
- A project versus a system perspective; only when the final MPO model was run to certify the LRP and TIP – against air quality standards – was there any comprehensive look at all projects proposed simultaneously.
- Lack of inclusion of operating needs and impacts
- Political rationale – projects favored by the Mayor or Governor came to the table quickly
- Limits of analytical forecasting and planning
- Non-systematic decision process and lack of clear objectives and evaluation criteria. Projects varied in key purpose: added capacity, air quality, economic development, local prestige. None of these objectives were ranked as more critical than the other, making setting a project hierarchy difficult.

<u>Paying for our infrastructure</u>. Infrastructure costs – capital and operating in the world's major capitals, Shanghai, New York, London,Tokyo are both immense and continuing. Strong business planning would insure continuing sources of funds for both. For New York, such long term business planning, planning that identifies not only costs, but revenue sources, does not exist. It does not exist because both State and Federal budgets operate on yearly cycles, even though they demand five year capital plans. There is also no formal, rational method for selecting projects by priority in New York City. An MTA transit project and a bridge replacement project would be evaluated by separate criteria. Should only limited matching local funds be available, the selection of which project "wins" would be political. It should be noted that the first cost estimate of both the East Side Access project and the 2nd Avenue subway Phase 1 were approximately $4B. This is equal to the current cost over runs of the projects listed in Table 1. Over runs play havoc with Capital Budgets. Because there is a limit to funding, over runs force project shrinking in scope, delayed (at added long term costs), or foregone. Transit projects that are delayed have a number of impacts; (1) they cause long term capital costs to escalate, (2) they delay transit being put into revenue service and (3) they have implications on system wide congestion.[vi] But, as our PCNY study showed, lack of rational planning and regional priority setting will have an even more drastic consequence in today's economic climate. Fewer mega projects can be built; dollars available for projects will shrink as escalating costs for a given project eats up available capital funds.

In the first decade of the 21st C. we have come to a limit in the efficacy of the traditional transportation planning process. Designed for a time when supply was urgently needed, questions of the environment, diminishing availability of both funds and tax payer willingness to pay and non-converging agency missions have made it necessary to revisit how transportation planning must be carried out. And now, in 2013, it has become critical to address sustainability and system resilience.

Part 2 – The new constraints. As noted above, the passage of ISTEA in 1991 demanded new attention by transportation planners and transportation agencies to the environment. But little was changed in the approach to planning, other than adding air quality certification to certification of the TIP and LRP. Academic approaches added to the improvement of travel demand forecasting, incorporating more sophisticated survey techniques and behavioral modeling, but, in the end, project selection remained as noted above – fiscally constrained and politically influenced. And while Global Warming and its consequences had been constant themes for discussion, little, if anything, had been done to address the environment in project discussions until Hurricane Sandy (2013). The devastation the hurricane and surge along the Atlantic Coast[vii] caused demanded that "resilience planning" be added to infrastructure planning. There are a number of significant factors that will necessitate modification or wholesale change of protocol to the mandated joint planning process. I will discuss a few of the most significant, indicating how they will impact transport investment decisions and how the planning process must be changed. Among these factors are:

- The global and local environment, including the emergence of sustainability, the impacts of global warming, resilience and the costs of energy.
- The changing generational culture influenced by adoption of smart devices and social networks
- The rapid integration of new technologies, including IT, remote sensors, cloud computing and big data
- Uncertainties in global economics

These factors are not necessarily orthogonal; there are interactions that have clear implications on transportation planning and project investments.

The rational transportation planning process has been based on an ability to measure demand on the basis of user characteristics, including demographics and the values (utilities) they place on having certain system attributes available for specific trips. The supply has been measured in terms of network capacity and modal attributes. Modeling has been based on bringing supply and demand into balance. But, in the last decade there have been significant trends in both demand and supply that will force planners to revisit their approach to transportation planning as an integral part of sustainable urban and community planning. The most fundamental change, as noted, has been the availability of real time information to both the user and provider. This information includes:

- Transport system information – vehicle location in the network, fare schedules, parking availability, all aspects of traffic and routing, weather factors. These are made possible by the large numbers of devices – including cell phones – that have GIS
- Activity information: - what's on, where, when, how much, how large a crowd, how to pay. This alerts both the consumer and the transport provider of needs based on attractiveness of a venue, location of a venue and modal use.
- Social networks: Social networks, e.g., Facebook, etc., have become the method by which groups communicate – using up to the minute information (see above) to make last minute travel/activity decisions. This of course does not hold for usually scheduled travel – such as work trips or school related travel, but use of social networks, increasingly influences non- scheduled travel.[viii]

Transportation planning has been carried out to improve access and mobility. Basically, from 1945-1980 this has meant increasing supply, resulting in great increases in Household auto ownership and in suburbanization. Global warming, sustainability and energy costs have slowed down and in some instances reversed this trend. For example:

- Large cities are experiencing population booms, while suburban growth remains flat or diminishing.[ix]
- Average VMT by millenials dropped 23 percent according to the 2010 census; these under 35s don't want to own or take care of cars and want to live where they have quick access to a city center or a dense inner suburb.

Access and mobility to this emerging cohort means less reliance on cars, more on transit, bicycles and walking, and living in communities where more of their activities are easily accessible. And, planning in urban areas supports this. As noted in US and World News[x], ""Census Data show that many close in suburbs linked to a city with strong public transit or well developed roadways are benefitting from strong city growth…New Census estimates show that most of the nation's largest cities… posting strong population growth.." In NY City, PlaNYC, the operational City Plan for 2030 has made sustainability the cross cutting planning criteria that must be addressed in every infrastructure and development plan. The immediate impact of the plan has been to soften major streets and intersections (most notably, Times and Herald Squares) , increase non - motorized means of travel (NYC has just implemented a bike share program similar to Paris), develop innovative Bus service and revamp the for hire vehicle industry. Developers now build "green" and use this a a selling point to residential and commercial clients. This national commitment to sustainability and environmental stewardship will have a significant impact on transportation planning as noted in the section below.

Sustainability as the underlying attribute of planning.

Transport increases access; access increases the demand for development. And development increases the demand for travel, the needs for additional energy and water and, increasingly, the need for new bandwidth for IT and communications. A basic transport planning question then becomes, "As we plan for new infrastructure capacity are the additional demands for carbon based travel, carbon generated electricity and water (and wastewater) use sustainable? While these questions were touched on in the necessary EIS accompanying capital plans, they have never been asked as direct coupled questions. There is a strong interaction between improved access, land use – population intensity and density, the concurrent demand for power and water and the ability of any region to sustain or even grow that demand over time.

The new transportation models must become interactive, iterative and coupled. We have data that show energy use/capita and water use/capita based on urban scale.[xi] While the 20th C impacts of highway construction on land use and sprawl are well known, the 21st C will be better known for using transportation investments, particularly transit investments to aid in densification. Hui notes[xii]that low energy building design in highly dense areas, decreases overall energy demand, shortens infrastructure (such as water links) decreasing the demand for water and promotes sustainability. Getman[xiii] noted that the differences in both energy use and greenhouse gas emissions between low and high density developments are extremely significant (about a factor of 2-2.5).

Existing (but not yet started) and future transportation projects must be tested against the land uses they serve and the new densities they will stimulate. These must then question what new demands on water and carbon based power will be demanded – and are these sustainable quantities. In this sense, the new approach to planning will be iterative and inclusive of transport modes that serve dense populations (non - motorized, public transport). There are many examples of successes in improved land use and reduction in anticipated demand for carbon based transport, including, Curitiba and its famous bus rapid transit, CrossRail in London – designed to sustain the densities of inner London, and the proposed new Smart Cities in China. In a modeling framework we would note that:

(1) Accessibility = f(transportation investment,e.g. change in capacity)
(2) Development = g(change in accessibility)
(3) Energy demand, water demand, bandwidth = h(development)

These simply put relationships hide the complexity of addressing how transportation infrastructure changes increase the urgency of examining regional energy supply (and source and cost), regional water supply (and source) and the ability (bandwidth) to use real time information to improve all aspects of infrastructure management and use. A new generation of transportation models must be developed, replacing the post WW2 supply-demand models we have used and evolved for so long.

Conclusions. The coupled relationships noted above change the paradigm of project centered planning – noted in part 1 of this paper, dependent on funding and political needs and shifts the emphasis to sustainability (and, of course, resiliency – a current surrogate for sustainability).

We have new tools, unthought-of until a few short years ago, including:

- The availability of real time data, and the use of it through smart devices, storage on the cloud (active remote servers) and an emerging set of algorithms to utilize big data
- The use of social networks – the ability to share in real time and among groups - information , attitudes and decisions

While extreme climate events (hurricanes, super tornados, periods of intense rain and drought) individually are not complete evidence of global warming, the impacts of these events (floods, property destruction, etc.) have changed, in a short period of time how we address land use planning. And, it forces us to address infrastructure planning. As noted, examples abound in the European Union and Asia of how to address sustainability. We need to study and integrate these methods into our own infrastructure planning.

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[i] Paaswell, R., "Approaches to Infrastructure Redevelopment, WTC, Lower NYC and the Region", Proceedings, ASCE 2nd International Conference on International Infrastructure, 2004

[ii] In fact, this trend has continued until now, with increases in population, jobs, economic output and transit ridership.

[iii] Berechman J., and R. Paaswell, "Evaluation, prioritization and selection of transportation investment projects in New York City", Transportation, Vol. 32(3), pp 223-249, 2005

[iv] Paaswell, R, A New Paradigm for Transportation Planning, Transportation Infrastructure: The Next Hundred Years, APA Planning Service Report, April 2009

[v] The author was asked to write several white papers for the "Ravitch Commission", a Governor appointed task force (2009) headed by Richard Ravitch to find solutions to the MTA funding issue. None of the many solutions – all well tried around the transit world – were politically acceptable.

[vi] The author conducted a study for MTA on project delay, estimating the costs on a variety of projects, Impact of Deferred Investments on Capital and Operating Budgets: A report to the MTA, UTRC, Nov, 2004

[vii] The author presented the impacts of the hurricane on New York and its transportation systems at a CNAM conference ," Les transports ferroviaires régionaux et locaux : comparaison France/Etats Unis", Paris, France, Nov. 2013

[viii] Examples showing how social networks have real influence on travel bahvior are found in, : T. Arentz and H. Timmermans, "Social Networks, Social Interactions and Activity Travel behavior, Environment and Planning B, 2007, U. Gretzel. " Do Social Media Influence our Travel Decisions", Univ. of Wollongong Research, 2011, and J. Silvis et al, " Social Networks and travel behavior", Conf. on Expanding Shpere of Social Behavior Research, Kyoto, Japan, 2006

[ix] US and World News , May 25, 2012

[x] "Urban Renewal", Big US Cities Showing Strong Growth", US and World News, May , 2013

[xi] Much of the data in this section comes from, A. Getman, "Transportation Planning Effects on Land Use, Energy and Water Infrastructure", Univ. Transportation Research Center, CCNY, May 2013.

[xii] S. Hui, "Low Energy Building Design in High Energy Cities", Renewable Energy 24, Pergamon, 2001

[xiii] Getman, op. cit.

Autonomous Vehicles: A Critical Tool to Solve the XXI Century Urban Transportation Grand Challenge

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Abstract

One of the fourteenth Grand Challenges that the United States National Academy of Engineering (NAE) has identified for the XXI century is improving urban infrastructure. According to NAE, the greatest challenge will be the integration of the different modes of transportation as a whole system, especially in large metropolitan areas. In the last decade, new technologies based on autonomous vehicles and information technology systems have made significant key breakthroughs on this field. The combination of high performance driverless cars with intelligent information systems could produce a powerful tool to reach new levels of optimization in urban transportation. This paper presents a holistic approach to solving public and private transportation challenges by using unmanned cars and intelligent information systems.

The paper also addresses the urban transportation challenge and the technologies available today, describe the multifaceted approach, and identify the advantages of its application. In a nutshell, this paper provides a systematic approach that XXI century engineers could use to create more eco-friendly, safe and sustainable transportation environments.

I. Introduction

The United States National Academy of Engineering (NAE) proposed in 2008 fourteen Grand Challenges for XXI century engineers. One of the fourteen challenges is “Restore and Improve Urban Infrastructure” in other ways by the design of engineering integrated transportation systems without making any difference between transportation methods but allowing all to be feasible, accessible and as efficient as possible (National Academy of Engineering). This Grand Challenge has been the result of tireless efforts and resources to accommodate our transportation needs in complex urban areas as optimally as possible with sometimes dubious results. These results could be seen for example, in highway capacity ratio, the total surface amount of vehicles that occupied a highway surface at optimal speed up to 100 km/hr. According to the data provided by California’s Performance Measurement System (PeMS) and studies performed at the California PATH Program Institute of

Transportation, a typical U.S. highway has a maximum occupancy per lane of 2,200 vehicles per hour representing 5% of total highway surface (Shaldover, Steven). This means that the other 95% of the highway surface is used as safety buffer area between cars due to the limitation of human driver abilities.

Another useful measure to quantify the effectiveness of the main American transportation network is the amount of time lost due to transportation congestions. According to the Texas Transportation Institute of Texas A&M University, in 2007 Americans spent 36 hours on average in car traffic congestions (Brandy, James). Moreover, focusing on the data provided by the U.S. Federal Highway Administration (FHWA) in twenty major urban areas of the U.S. the daily amount of congestion for 2010 was 4:38 hours (US Department of Transportation). These three values indicate that the U.S. freeways and highways networks are absorbing a lot of resources that could be used more efficiently in the future if a better combination of technology and resources could be found. Fortunately, in the last eight years, technological breakthrough advances have been made in autonomous vehicles and Intelligent Transportation Systems (ITS) fields.

These advances can contribute to starting to move from a human control oriented device system to a more efficient automated, self-decision making vehicle system. This future step will provide new tools to transportation engineers in order to design a better and optimal transportation system. The benefits of moving from human control devices to self-decision-making machine devices are countless. However satisfying the population transportation needs without jeopardizing enormous capital resources is a major challenge. At the same time, the approach will reduce human errors from accidents, decrease auto insurance premiums due to fewer car accidents, cut health costs, decrease road deaths around the U.S., and reduce gas consumption dropping the nation's expenses on oil needs for transportation. The wholistic approach of the NAE Grand Challenge requires also an agreement between all stockholders of the transportation game (transportation authorities, drivers, public transportation users, transportation engineers, even transportation vehicles manufacturers and insurance car companies) to solve this complex problem in an optimal way.

II. Literature Review

The literature on autonomous vehicles is very extensive, since a lot of research has been done in last three decades, especially in Europe and the U.S. The following two large public programs sponsored research and teams to develop this technology:

a) In Europe, the Prometheus Project involved more than twenty manufacturing car companies and important research institutes such as the Argo and VisLab. In the 80s, Dr. Alberto Broggi from VisLab, Dr. Ernst Dickmanns from Navlab, and Dr. Charles Thorpe from VamP Institutes were the pioneers of the autonomous vehicle technology. The three of them designed and built self-driving vehicles (Urmson, Chris). VisLab pioneered the development of a self-driving car technology based on artificial intelligence and vision cameras while the other laboratories simply used Lidar, Ladar radars, IR rangers, cameras and GPS. During the 90s, these research teams built prototypes and tested them in highways at 130 km/hr (Urmson, Chris).

b) In the U.S., and for more than twenty years, the Path Project at the University of California, Berkeley has developed an automatic highway technology, which emphasizes on collaborative technology between autonomous vehicles and the highways (Shladover, Steven). As a result, a large number of research papers on cooperative vehicle-highway automation systems have been published. Also at Berkeley, Vason P. Srini at the Wireless Research Center envisioned autonomous navigation in urban environments using wireless technology that communicates the road, the self-driving car, and the intelligent transportation system.
However, the most important advance in the U.S. was sponsored by the U.S. Defense Advance Research Project Agency (DARPA) through its Grand Challenges in 2003, 2004, and 2007. Research teams from all over the world developed the most efficient and reliable autonomous vehicle on different environments at the DARPA Grand Challenges. Also, the industry was able to have a prototype ready to be self-drive in any urban or highway environment without major issues. Afterwards, Google decided to hire the winners of past DARPA Grand Challenges. Today, this research team is leading the race with the Google car that has been authorized by the Nevada Department of Transportation to be tested and driven in its roadway system thanks to the first U.S. driven license for driverless cars (Fox News). However, Google has not published any research article about these advances due to its secret research policy.

III. The "Transportation Game"

The simplistic approach to the transportation problem will answer how a person can go from point A to point B using the most optimal mix of transportation resources available. This simple approach becomes completely useless when we add the large number of stockholders that participate in this "game". To increase the complexity of the problem, our transportation system is based in human decisions, increasing the number of variables to be solved and making sometimes public transportation an incomplete solution to the problem. In fact, urban environments where authorities have invested heavily in public transportation still suffer from private car overuse that in some cases has persuaded authorities to ban the use of private cars in city downtowns (Waterfield, Bruno). Automobiles so far are the best individual choices due to the auto's feasibility to transport individuals from point A to point B. Moreover, motor vehicles can be the perfect mix to massive public transportation as first and last mile vehicle. This car flexibility makes researchers consider automobiles an important tool in the transportation game, in urban or non urban environments.

The large amount of resources our societies are spending trying to satisfy their transportation needs, measured in capital and operational costs, and the negative outcomes calculated in productivity loss, human loss, and environmental damage have convinced authorities to develop research studies trying to find optimal solutions to the “transportation game”. In past decades major advances in car mechanics, public transportation and Intelligence Transportation Systems (ITS) have made some improvements. However, the major problem is still not solved because of the insatisfaction of the transportation demands versus the supply available as the demand tends to change faster than supply. These resources can be measured in many ways, but one clearly would be the freeway and highway capacity and the time lost due to congestion. Both measures indicated the optimal ability of the transportation system to reach people transportation needs and the cost that the society needs to spend. If a most optimal solution can be found, more resources can be liberated from the transportation game and instead be used on new matters that can contribute to increased wealth of the country.

Most of the researchers agreed about the benefits of using autonomous vehicles into our transportation society. In general, the benefits of autonomous vehicles are as listed:

- Fewer accidents. Autonomous vehicles are more reliable than the human drivers, due to its special design and instruments more accurate than limited human perceptions that are not designed for high speed. Less accident cars will contribute to reduce the health cost of the society.
- Better gas consumption. Data provided on driverless car research denoted a gas savings from 20% to 50% (Frazzoli, Emilio), which means less dependency of a limited natural resource as petroleum.
- Better cruise performance. Because machines have better performance than humans a high or low speed, driverless car allow higher highway occupancy ratio, increasing the maximum occupancy per highway lane in maybe two or three times by reducing the buffer space within cars (Shladover, Steven).
- Less need for parking facilities in urban areas. Because the car is driverless, allow to pickup and drop-off) people without searching for parking space. This characteristic can allow having a permanent pool of cars driving around downtown cities to satisfy some of the people transportation needs.
- Driverless cars can be shared increasing resource efficiency and reducing environmental impacts of transportation needs. Increase the sustainability of our societies by less air pollution impact and more environmental friendly, especially in large urban metropolitan areas. Also, sharing this technology into few costumers will demand fewer resources, less capital cost for the transportation authorities.
- Increase the amount of people time for work or enjoy by liberating all human driving activities. This benefit can increase people’s productivity.
- Reduction of the insurance premiums and in general decreasing the car operational costs due to less accidents and better car performance.

- Allow to older and disable people use a reliable transportation means.

Following the NAE Grand Challenge, the best approach to solve this complex problem is to adopt a wholistic resolution, where all systems will interact together. The general idea is to synchronize all the transportation methods at once into one unique system based on autonomous vehicle as a cornerstone. The autonomous vehicle will be the link of this online decision making system. The vehicle will provide input data to the system and will receive it as well, adopting the optimal route to go to its destination.

Moreover, the autonomous vehicle becomes the connection between all systems by intercommunicating the autonomous vehicle and other vehicles or between autonomous vehicles and I.T.S. in order to inform about infrastructure status, traffic situation and best available route to reach the destination. The communication technologies used on this wholistic approach based on driverless cars are as listed:

- Intercommunication car to car. Cooperative autonomous cars (Shladover, Steven)
    - Interchange information regarding location and destination based in GPS location and smart-phone devices location tools.
    - Ability to share same route and drive closer forming convoys as car trains, increasing highway occupancy.
    - Increase coop0erative efforts between driverless cars regarding better drive performance, car mechanics, or car status by using stochastic optimization methodologies.
- Intercommunication car to infrastructure (ITS)
    - Double direction communication car to infrastructure in order to inform about traffic conditions, weather situation, future destination and predictable paths. The system will learn about people transportation needs and can pro-active prepare the infrastructures for that.
    - Future traffic status and time delays based in historical data collected. Also the system can introduce learning machine techniques to avoid past mistakes.
    - Infrastructure status. Devices can be installed in the infrastructure to inform ITS system and autonomous vehicle about the structure status and condition of the infrastructure.
- Intercommunication car to Internet/Web 2.0
    - Software integration between autonomous car and smart devices such as smart-phones or table pc.

   - Autonomous cars became portable routers providing access to internet. The driverless passengers will have internet access during their trip.

   - Smart-phone applications to provide driverless rental car or autonomous taxi vehicle for instantaneous urban transportation. A pool of cars can be driven autonomously along city downtowns with specific lines to pickup and drop-off costumers around the city limits

   - Ability to share cars thanks to social networks and instantaneous communication. People can ask for a common ride service through social network. Same autonomous car can share the route with two or more people that live in the same area and have the same transportation needs.

   - All data can be stored in the cloud system, making available to individual autonomous vehicle get access to large amount of data to choose the best transportation option online, on time. It can be combined with public transportation services.

   - In case of accident, an autonomous car can provide status of the car, and location to emergency services on line.

- Intercommunication between car and public transportation management centers.

   - Autonomous vehicles as the first and last mille for public transportation systems, which will traduce in an integration of the driverless car into public transportation system.

   - Autonomous vehicle can access to public transportation data centers, where can have information of the public transportation services, status, location and occupancy. This information will be critical to a perfect combination between private autonomous cars and public transportation services.

   - Public transportation management center can account number of passengers provided by autonomous vehicles. Can adapt better the supply to potential daily demand base in historical data, and increase frequencies if it is needed.

These communications have the goal to feed our system with the deal of better match the curve demand of people transportation needs to the less flexible supply in transportation resources available at a specific moment on time. This system with all input data will try to alleviate the daily potential congestion that our urban transportation network deals every single day. Congestion defined as the lack of transportation supply services at a specific place and time. Using this wholistic approach will make more available resources and alternatives to the congested infrastructure that otherwise will be less used.

IV. Conclusion

By allocating on the best way possible transportation demands with supply transportation resources this intelligent network system will be able to satisfy people transportation needs from point A to point B. Sharing routes, changing information between transportation systems, using social network to share cars, smart-phone applications to solicit a momentarily rental car for short urban transport are some of the beneficial uses of applying autonomous vehicles in all transportation system.

The research interest has been so far focus in the application of autonomous vehicles, but a combination of all technologies need be developed to reach the maximum potential of autonomous vehicles.

However, not only engineers need to work together, also authorities and industry leaders need to work together in order to establish clear rules for autonomous vehicles, lower the insurance premiums, and liberate resources that can be applicable in other fields. All these characteristics can drive for a more sustainable urban environment, and allow developing nations to have affordable transportation network without jeopardizing more natural resources.

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The Self-Powered Streetcar Revolution
The new affordable transit option for cities worldwide

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ABSTRACT
With the tough economic climate world-wide, many cities that had contemplated and even scheduled heavy rail or light-rail projects have either put them on hold or scrapped them altogether. Enter the resurgence of the streetcar, where self-powered technology could bring back the mode of transportation that was dominant in the early 20th century.

There is a very quiet revolution taking place to introduce streetcars powered by batteries, hybrids and even solar and wind power. The beauty of these systems is the elimination of overhead wires, power stations and additional transformers. These systems can save anywhere from 40 to 50 percent in capital and operating costs as compared to traditional LRT—with operating characteristics are approaching that of LRT in terms of speed, range and power.

This paper will explore the latest in self-powered streetcars.

INTRODUCTION

The city of Oranjestad, Aruba, presented planners and engineers on an American Planning Association-sponsored trip with a problem: Tourists were not making their way to Aruba's main street of Caya G.F. Betico Croes. These tourists, mostly Americans, were arriving by cruise ships. The Caya is about a three-quarter mile walk away from the docks—but out of sight distance. Most tourists don't think to go there. Instead, they shop around the terminal docks or take cabs up to the hotel district.

The solution that was proposed by the Prime Minister of Aruba was to build a tramline to link the cruise ship terminal to Caya G.G. Betico Croes. Tram service could transport tourists from the cruise terminal to main street Oranjestad within a few minutes. With the tough economic climate, however, many cities that had contemplated and even scheduled light-rail projects have either put them on hold or scrapped them altogether. New Jersey, Ohio, Florida, and Wisconsin have pretty much abandoned their rail programs. Cost is the single biggest issue. The 26 km light rail transit (LRT) Purple Line in Maryland, for instance, is estimated to cost $1.8 billion—or more than $100 million per mile.

SELF-POWERED STREETCAR TECHNOLOGY

Recent technological innovations, however, are providing another option for cities with problems like those of Oranjestad: The self-powered streetcar. In fact, this type of streetcar—a battery-powered, self-propelled vehicle with no need for external power sources or stations—is already in place at The Grove in Los Angeles, a beautiful shopping oasis built by the developer Rick Caruso. The manufacturer of The Grove's self-powered hybrid electric streetcar, the California-based company TIG/m, is rapidly expanding into receptive urban markets world-wide: In addition to two battery streetcar systems in Los Angeles and San Antonio, Texas, TIG/m will soon be operating in Mexico and Qatar.

From the perspective of city officials, the beauty of TIG/m's systems not is only in the elimination of wayside power systems, but also in the potentially tremendous cost savings when compared to LRT. While TIG/m's operating characteristics are approaching that of LRT in terms of speed, range and power, TIG/m streetcars have an onboard battery packs that charge overnight with an onboard clean fuel generator for supplementary power (refer to Figures 1 and 2). Battery-powered propulsion eliminates the need for transformers, substations, and overhead wires. Battery-powered propulsion also obviates any public resistance to new unsightly power lines, poles, substations, and associated construction. Consequently, these systems are estimated to save anywhere from 40 to 50 percent in capital and operating costs.

Figure 1. Éilan Streetcar No. 23.

Figure 2. TIG/m ViaTran.

For the past 115 years, electric street railway systems have relied on an unlimited source of off-board power—usually over-head catenary systems (OCS)—which has led to extremely heavy vehicles and high power consumption being industry standards. As a result, it is impossible to provide enough on–board power storage for a standard streetcar vehicle—one built under the assumption of an unlimited off-board power supply—to complete a full day of service in a municipal setting. Yet rail-borne vehicles, and streetcars in particular, are the perfect candidate for electric self-powered application as long as the vehicle has been designed with low power consumption and maximum power regeneration in mind as shown in Figure 3.

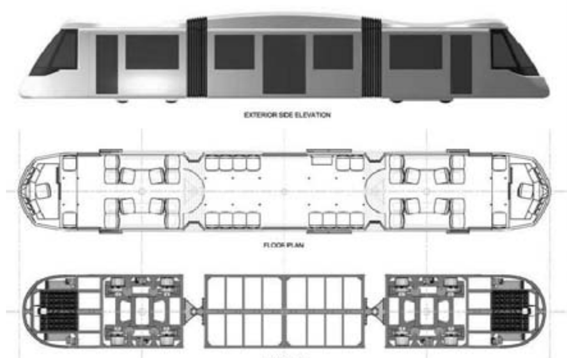

Figure 3. TIG/m Modern Low-Floor Streetcar Design

TIG/m has spent the past seven years designing every system and sub-system in its streetcar to operate at minimum energy consumption while maximizing the necessary power and safety required of a transit vehicle. TIG/m streetcars operate on rails, but require no overhead or other external power supply. They operate entirely on an internal battery/hybrid system.

The extremely low coefficient of friction between a steel wheel and steel rail means that less energy is required to overcome inertia during acceleration, less energy is required to keep loads in motion, and more energy is recovered during regenerative braking. The required ratio of battery weight to total vehicle weight is substantially less in a streetcar than in any rubber tired vehicle.

The heart of the system is a CAN BUS based control system that monitors all operator controls and sends commands to the "energy smart" propulsion system, braking systems, and ancillary devices. The system can determine and maintain proper speed, acceleration rate, deceleration rate, torque, and prevent slipping on wet or frosted rails. It can determine if there is a problem and decide whether to "ask" for service, bring the streetcar to a controlled stop to shut off the malfunctioning component or and shut down the entire vehicle. All these parameters may be predetermined by the end user or adjusted at any point.

The power of the system is supplied by four, three-phase A/C traction motors wound to provide high torque at low speeds indefinitely. Each traction motor provides data to the motor controller, which is then forwarded to the control system where comparisons are made between each motor and its operational parameters. Each traction motor's performance is evaluated four times per second by the control system to keep all four motors in synchronization at all times.

TIG/m self-powered streetcars uses regenerative braking, a stored-energy traction system that sends power back to the batteries whenever the motors are told to reduce speed. The heat and mechanical energy typically wasted by contemporary mechanical brakes is converted to provide storable energy extending the run time of the streetcar. Mechanical brake wear is nearly non-existent and the need for lengthy stops for shore power is reduced, which extends the total daily "in service" time.

The computer-controlled battery management system monitors each battery within the system and can isolate a single battery within either of the two battery bank arrays and tailor the charge to accommodate it. This prevents them from becoming terminally out of balance and helps eliminate premature battery failure. Redundant batteries ensure the streetcar will return to its base without assistance in the event that single battery or bank of batteries fails.

The TIG/m self-powered streetcars can also be augmented with an on-board power generator of a specific kW rating. The generator, as shown in Figure 4, is a self-contained system powered by renewable fuels that never directly powers the traction motors but rather recharges the batteries in service.

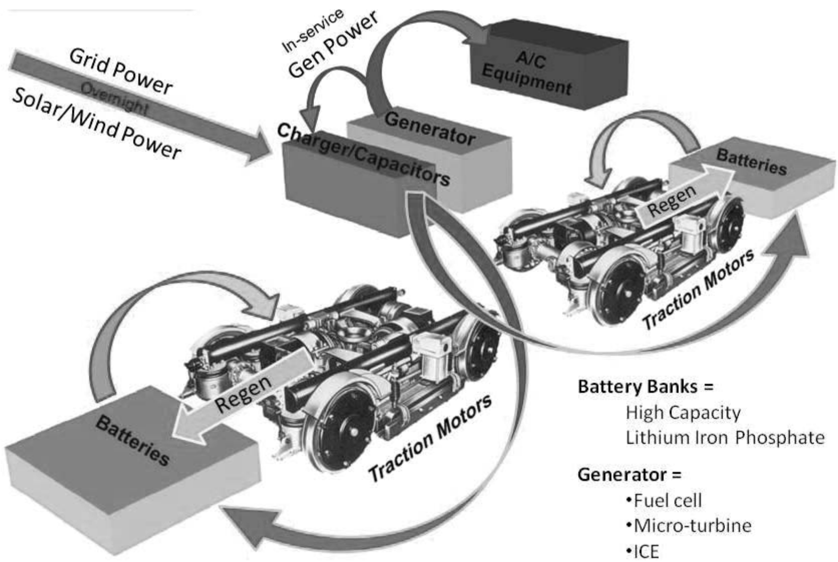

Figure 4. How TIG/m Self-Powered Streetcars Work.

TIG/m systems do not require external electrification, resulting in dramatically lower infrastructure installation costs. Current streetcar technology, requiring overhead wire and its supporting structures, feeder lines and substations, costs approximately $650 per track foot to install. Eliminating these wayside systems means that streetcar infrastructure can be installed for up to 40 percent less in initial capital expenditures, while eliminating unsightly wires and substations across the city. By cutting out the need for overhead transmission lines, TIG/m is also reducing the environmental impact of streetcar systems, construction waste, electrical transmission line loss, and stray current problems. Lifetime infrastructure maintenance costs are also significantly reduced. The power calculations for TIG/m streetcars are detailed in Figure 5.

18-hour service day

Budget

LiFePO4 Battery	=160 kW	=160 kW
PEM Generator	=14 kW x 18 hr.	=252 kW
Regenerative braking:	30% of traction consumption	=58 kW
Total	Daily Total	470 kW

Consumption

Traction	=18 kW x 18 hr. (.6) = 324 x .6*	=194 kW
A/C	=8 kW x 18 hr.	=144 kW
Ancillary Equipment	=1 kW x 18 hr.	=18 kW
	=27kW x 18 hr Daily Total	356 kW

*This calculation is based on a very conservative service-day split of 60%/40% between drive time and dwell time. PEM generator operates 100% of the service-day (drive + dwell).

Resulting Surplus

Budget	470 kW
(minus) Consumption	356 kW
(equals) Surplus	**114 kW**

Daily Battery Depletion

LiFePO4 Battery	160 kW
(minus) Surplus	114 kW
(equals) Depletion	**46 kW (30%)**

Recharge Time

Charger rated 400 VDC @ 100 A

From 70% to full charge	= 1.5 hr.
From 50% to full charge	= 2.3 hr.
From 25% to full charge	= 3 hr.
From 0% to full charge (conceptual)	= 4 hr.

PEM Fuel Cell Generator refueling by bottle-swap.

Two sets of hydrogen bottles are utilized. One set is refilled during the day. At night the depleted set is swapped out during battery charging. Swap time approximately one hour.

Figure 5. Modern Low-floor Streetcar Power Calculations

CONCLUSIONS

Unlike electric street railway systems that have relied on an unlimited source of off-board power—usually over-head catenary systems (OCS)—TIG/m systems do not require external electrification, resulting in dramatically lower infrastructure installation costs. Traditional streetcar technology, which requires overhead wire and its supporting structures, feeder lines and substations, costs approximately $650 per track foot to install. Eliminating these wayside systems means that TIG/m streetcar infrastructure can be installed for up to 40 percent less in initial capital expenditures, while eliminating unsightly wires and substations across the city. By cutting out the need for overhead transmission lines, TIG/m is also reducing the environmental impact of streetcar systems, construction waste, electrical transmission line loss, and stray current problems. Lifetime infrastructure maintenance costs are also significantly reduced. As a result of these technical innovations, TIG/m self-powered streetcars bring new and affordable transit options to cities across the world, from Aruba to Qatar.

The Role of Electric Drive Transit Technologies in Reducing Greenhouse Gas Emissions

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Abstract

Accounting for 71 percent of the petroleum consumption, the U.S. transportation sector generates about one third of nation's greenhouse gas (GHG) emissions. While public transportation is a relatively small portion of the overall transportation sector it is not insignificant, producing approximately 10.9 million tons of GHG emissions annually. Reducing energy consumption and GHG emissions of public transit vehicles can provide substantial cost savings and generate significant environmental benefits.

The U.S. Federal Transit Administration's (FTA) strategic vision focuses on the wide adoption of the innovative electric drive transit technologies as an ultimate alternative to traditional diesel-powered transit vehicles. To implement electric propulsion transit technologies, FTA developed the Electric Drive Strategic Plan (EDSP) that provides for a wide range of activities for the development, demonstration, and evaluation of the advanced electric drive technologies including propulsion systems, components, accessories and infrastructure. The ultimate goal of this plan is to achieve commercial availability of zero tailpipe emission, highly efficient and affordable transit vehicles by 2030, leading to drastic improvements in the energy efficiency and GHG emissions of the U.S. transit fleet.

Implementing the goals of the EDSP is projected to save 4.9 billion diesel gallon equivalents of fuel and eliminate 98.7 thousand tons of NOx and 52.9 million tons of CO_2 in tailpipe emissions over the period from 2010 through 2030. The implementation and wide adoption of electric drive transit technologies in the U.S. is expected to significantly reduce public transportation fuel costs and provide environmental benefits valued at $1.4 billion over the 20-year period.

1. Introduction

The United States' industrial strength, productivity, mobility, and high level of income per capita depend on the availability of affordable, accessible, and reliable sources of energy. While the U.S. has relatively abundant domestic sources of natural gas and coal, more than half of the nation's petroleum is imported. Instability in oil-producing regions of the world along with new demands for energy from the developing countries have led to renewed national concern about the security of America's energy supply.

In addition to energy security, the issues of air quality and climate change are also becoming extremely relevant in the recent years. The U.S. transportation sector consumes almost three-quarters of the nation's petroleum and generates about one third of the nation's GHG emissions (US DOE, 2009). Therefore, national energy policy has focused heavily on transportation, and public transportation can play a vital role in reducing energy consumption and GHG emissions.

In order to address the nation's energy security and environmental concerns, the U.S. Federal Transit Administration (FTA) developed a 20-year plan that provides for the adoption of electric propulsion technologies on transit vehicles. The Electric Drive Strategic Plan (EDSP) outlines a range of activities for the development, demonstration and evaluation of the advanced electric drive technologies with an ultimate goal of achieving the commercial availability of zero-tailpipe emission, highly efficient and affordable bus and rail transit vehicles by 2030.

The current paper will present the projected environmental benefits and cost savings associated with implementing electric drive technologies on public transit vehicles, as envisioned in the FTA's EDSP, measured in constant 2010 dollars.

2. Transportation Sector Energy Challenge

An abundant supply of affordable petroleum during the 20-th century has fueled the growth of the world's transportation system, offering Americans an incredible level of mobility. The demand for energy is growing globally, and competition for energy resources is likely to increase as developing nations achieve higher industrialization of their economies and with traditional energy sources becoming more scarce.

The worldwide increase in petroleum demand is largely driven by technological and economic progress in Asia. In the next 20 years, China, India, and other developing nations in Asia are expected to experience a combined economic growth of 5.8 percent per year, resulting in a 2.7 percent average annual increase in the region's liquid fuel demand (IEA, 2007).

According to the Energy Information Administration (EIA), 62 percent of petroleum, consumed by the U.S. transportation sector, is imported (EIA, 2009). Considering that the U.S. currently holds approximately 2 percent of global petroleum reserves (BP, 2010), the current heavy reliance on a single, finite source of energy for transportation presents a challenge for the nation's energy security.

Why Public Transportation

While public transportation is a relatively small portion of the overall transportation sector, it plays a vital role in reducing energy consumption and greenhouse gas emissions. There are three widely accepted opinions on how to reduce greenhouse gas emissions from transportation: 1) make cars more efficient, 2) use alternative fuels that release less amount of greenhouse gas, and 3) provide more transportation options so that the Americans reduce usage of their cars for some or all of their travel needs. In fact, effective reduction in transportation energy consumption and emissions should involve all three approaches. The use of public transportation contributes to that goal by reducing greenhouse gas emissions and fuel consumption (by displacing cars on the road) without reducing mobility. By the estimate of the American Public Transportation Association, the use of transit saves 4.2 billion gallons of fuel and 37 million metric tons of carbon dioxide emissions annually, while also supporting 1.7 million jobs (Miller, 2009). Therefore, transit, while relatively a small part of the transportation sector, is not insignificant in terms of its impact on fuel consumption and emission reduction.

Why Electric Drive

There are several potential transportation technologies/fuels that, to a varying degree, may address the environmental and energy security concerns of traditional petrol-based fuels, including compressed natural gas (CNG), hybrid-electric, electrification of accessories, battery-electric, hydrogen fuel cell, and others. While some technologies are only undergoing proof-of-concept demonstrations, others are already being mainstreamed by widespread adoption and enjoying economies of scale in production. Still, none of the alternative technologies are without drawbacks. Careful consideration is required while selecting the technology that can provide long-term solutions for the current energy and environmental challenges.

One potential alternative technology, that is gaining popularity lately, is compressed natural gas (CNG). CNG transit technology provides fuel cost savings and emissions benefits, and can provide a viable short-term alternative to the traditional diesel buses. However, this technology is not without its drawbacks.

While CNG vehicles provide significant improvement in terms of emission reduction over the regular diesel engines, CNG is not totally “green”. Natural gas consists mainly of methane, which is a greenhouse gas itself. If leaked into the atmosphere, it traps even more heat than CO_2 does. Also, the pressurized nature of the fuel makes refueling process more complicated and raises safety concerns. Finally, while natural gas is currently relatively abundant, it is not a renewable resource and in that sense is not much different from the petroleum-based fuels.

The U.S. Federal Transit Administration is considering to focus on the development of energy-efficient zero emissions electric drive transit systems as an ultimate alternative to diesel-powered public transportation vehicles, while relying on hybrid, CNG, and other interim technologies in the short-term. Electric drive system is a clean and efficient technology that has the potential to reduce energy consumption, decrease the dependence on foreign petroleum products, reduce air pollution and noise, as well as increase the popularity of public transit.

With a strategic approach to increasing the use of electric drive for transit, the industry can be positioned to take full advantage of improvements to the electrical grid. “Smart grid” technologies are already being demonstrated that will allow for the off-peak purchase and storage of energy, two way digital communications to allow for the selling back of “excess” energy to the grid, and load leveling strategies.

3. Electric Drive Strategic Plan (EDSP)

In order to implement electric propulsion technology on transit, FTA developed the Electric Drive Strategic Plan (EDSP) that provides for a wide range of activities for the development, demonstration, validation and ongoing evaluation of the advanced electric drive transit technologies. The ultimate goal of this plan is to achieve commercial availability of zero emission, highly efficient and affordable bus and rail transit vehicles by 2030.

FTA’s plan outlines specific activities and focus areas that provide for the introduction and improvement of advanced electric drive and related technologies to enable commercially viable transit vehicles with significantly higher efficiency, lower emissions, and superior performance. Specifically, the EDSP sets three goals:

1. Triple fuel efficiency of 40-foot transit bus and rail transit systems

2. Decrease transit vehicle tailpipe emissions, achieving bus-level emissions equivalent of at least one-half reduction in emissions from 2010 EPA heavy-duty engine standards

3. Achieve superior performance of new transit vehicles.

EDSP implementation also provides for the continued development and use of other advanced transit technologies, such as CNG and hybrid, as an interim solution in the short- to medium-term.

4. Methodology of the Analysis

The analysis presented in this paper compares projected GHG emissions and costs, associated with operating the U.S. transit fleet (both bus and rail) with and without the implementation of the electric drive technologies outlined in the EDSP. The assessment is based on the comparison between the projected transit fleet under the scenario of implementing electric drive technologies, and the status quo that assumes no implementation of the EDSP.

“EDSP implementation” scenario estimates emissions and costs of the transit fleet resulting from changes in transit fleet composition, improvements in fuel efficiency, improvements in emission rates, changes in the cost of different types of fuels, as well as changes in vehicle operating costs as a result of fully implementing the goals of the FTA’s Electric Drive Strategic Plan. “No EDSP” scenario, used for the comparison, estimates emissions and costs of the fleet assuming continued historic growth of the nation’s transit fleet, but constant fleet composition, constant fuel efficiency, and constant operating costs over the entire projection period.

5. Benefits of Adopting Electric Drive Technologies on U.S. Transit

Under the no-EDSP scenario, the transit fleet is assumed to grow proportionally at a constant annual rate over the period from 2008 through 2030, with all types of vehicles/systems maintaining their relative shares in the fleet. The bus fleet is projected to reach 88,000 vehicles by 2030, or grow by 41.4 percent, which is equivalent to 1.6 percent per year over the period from 2008 through 2030. The rail fleet is projected to grow to 24,300 cars by 2030, or grow by 26.2 percent, which is equivalent to 1.1 percent per year over the period from 2008 through 2030.

Under the EDSP implementation scenario, transit fleet is expected to shift towards significantly higher usage of alternative-propulsion vehicle technologies. For the bus fleet this means higher usage of CNG, hybrid electric, battery electric, electrified accessories, and fuel cell vehicles with a corresponding decrease in diesel-fueled fleet. The largest growth is projected for fuel cell buses, battery electric vehicles, and buses with electrified accessories. These types of buses will grow by an average annual rate of 31.9 percent, 24.9 percent, and 22.8 percent, respectively, over the period of 2010-2030.

For the rail fleet, implementing EDSP means expansion of rail modes with electric propulsion. The light rail fleet is expected to grow by 73.4 percent over the period of 2010-2030. The commuter rail fleet will grow by 36.3 percent, and the heavy rail fleet will grow by 7.8 percent over the same time period, as a result of implementing EDSP. The share of electricity-powered commuter rail is projected to increase from 70.0 percent to 84.4 percent over the period of 2010 through 2030 as a result of implementing EDSP goals.

Figure 1 and Figure 2 present projected bus fleets under the scenarios of “No EDSP” and “EDSP Implementation,” respectively, over the 2010 through 2030 timeframe.

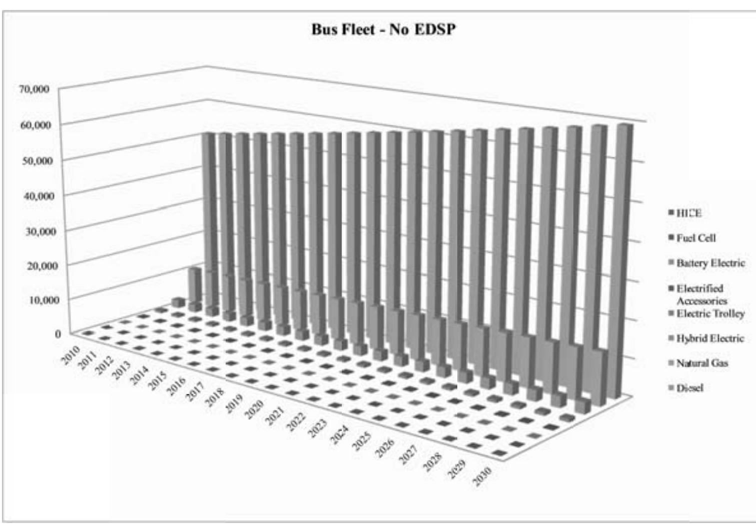

Figure 1 – Projected Bus Fleet – No EDSP, 2010-2030

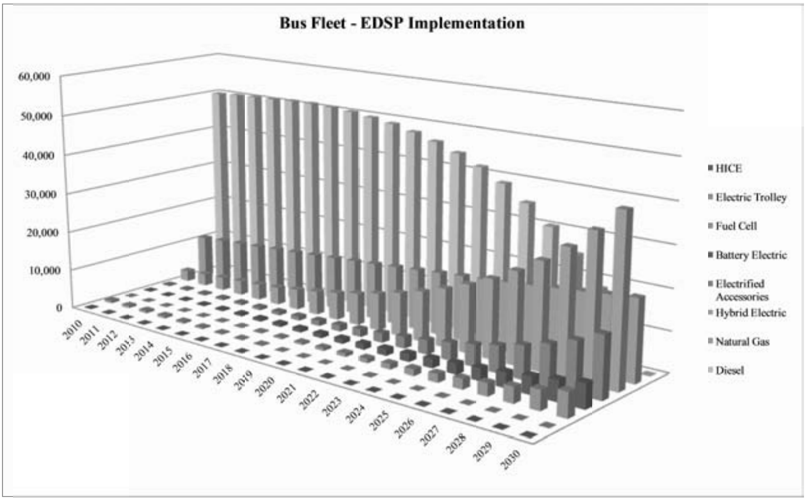

Figure 2 – Projected Bus Fleet – EDSP Implementation, 2010-2030

Fuel Consumption

Implementation of the EDSP provides for the adoption of advanced propulsion technologies that result in significant improvements in fuel consumption over the period of 2010 through 2030. Assuming that no significant additional efficiencies will be realized without implementation of the EDSP, Figure 3 shows fuel savings expressed in diesel gallon equivalents (DGE) over the 20-year period.

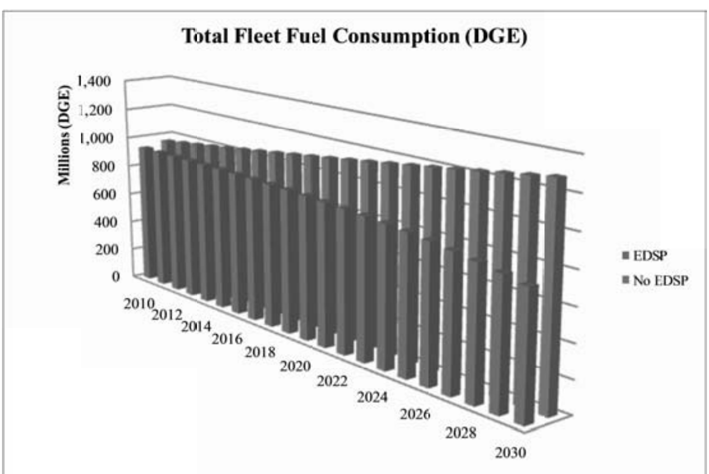

Figure 3 – Transit Fleet Fuel Consumption Comparison (DGE)

The analysis indicates that achieving the EDSP goals is projected to save 4.9 billion DGE of fuel over the period from 2010 through 2030.

Table 1 presents the projected change in the consumption of different types of fuel (diesel, natural gas, electricity, and hydrogen) as a result of EDSP Implementation over the period of 2010 through 2030.

Table 1 – Change in Fleet Fuel Consumption: EDSP vs. No EDSP*

Year	Diesel (million gal)	Natural Gas (million ft^3)	Electricity (Gwh)	Hydrogen (tons)
2010	-26	86	-140	212
:				
2015	-97	331	-495	522
:				
2020	-190	617	-847	2,399
:				
2025	-322	953	-1,127	7,505
:				
2030	-534	1,341	-1,299	25,296
Total:	***-4,641***	***13,705***	***-16,762***	***116,060***

* Negative numbers mean decrease in fuel consumption as a result of EDSP implementation. Positive numbers mean an increase in fuel consumption as a result of EDSP.

The results indicate that implementing the EDSP will result in a total reduction in the consumption of diesel fuel by 4.6 billion gallons and in a total decrease in the consumption of electricity by 16.8 terawatt-hours from 2010 to 2030. Total consumption of natural gas and hydrogen is projected to increase by 13.7 billion cubic feet and 116 thousand tons, respectively, over the same time period as a result of achieving the goals of the EDSP.

Emissions

The implementation of the EDSP goals will influence the total amount of emissions from the transit fleet based on the amount of fuel consumed. The following analysis considers tailpipe emissions of NOx and CO_2. Only diesel, natural gas, hybrid electric buses, and buses with electrified accessories have tailpipe emissions within the bus fleet. For the rail fleet, only the diesel-powered commuter rail is assumed to have emissions. Table 2 presents the change in GHG emissions for the entire transit fleet (bus and rail), as a result of implementing EDSP and reports the monetary value of the emission reduction over the projection period. Emission reductions are valued at \$21 per ton of CO_2 and \$2,600 per ton of NOx, as suggested by the Environmental Protection Agency (EPA) and Energy Information Administration (EIA).

Table 2 – Change in Transit Fleet Emissions as a result of EDSP

Year	NOx (tons)		CO_2 (tons)		Emission Cost Savings (Millions of $)
	EDSP Reduction	Cumulative Benefit	EDSP Reduction	Cumulative Benefit	
2010	2,072	2,072	281,661	281,661	$11
:					
2015	4,518	20,963	1,063,789	3,986,286	$138
:					
2020	5,283	46,272	2,126,049	12,332,801	$379
:					
2025	5,291	72,866	3,691,104	27,379,201	$764
:					
2030	5,080	98,708	6,263,688	52,987,085	$1,369

The analysis indicates that implementing the EDSP goals is projected to eliminate 98.7 thousand tons of NOx and 52.9 million tons of CO_2 in tailpipe emissions from 2010 through 2030. These emission reductions are worth $1.4 billion ($1.2 billion for bus and $0.2 billion for rail transit).

Total Cost Impact of the Electric Drive Strategic Plan

In addition to environmental benefits, in the form of emission reduction, electric drive technologies also provide long-term reductions in capital and operating costs for the transit agencies. The current analysis considers how the implementation of electric drive transit technologies will affect capital, operating, and fuel costs of the transit fleet over the period of 2010 through 2030. The results are presented both in annual and cumulative terms to provide a better picture of the long-term impact of wide adoption of electric drive transit technologies.

Fuel costs are calculated using long-term fuel price projections reported by Energy Information Administration 2011 Annual Energy Outlook (AEO-2011) (EIA, 2011). The future price of hydrogen for powering fuel cell vehicles is estimated using the methodology developed by the California Energy Commission (Bahreinian, 2009). In order to account for potential variability in the cost of fossil fuels, several energy market scenarios were considered, including the reference case, high economic growth, low economic growth, high oil price, low oil price, high cost of renewable fuels technology, and low cost of renewable fuels technology, as reported by AEO-2011. However, only the reference case scenario is discussed in the current paper.

The cost estimates show that implementation of the EDSP goals will result in higher capital and operating costs of the transit fleet (mostly for bus fleet), compared to the "No EDSP" scenario, until 2014. Starting in 2015, the EDSP is expected to generate savings in terms of operating costs, compared to the "No EDSP" scenario, and is projected to recover all operating cost losses from previous years by 2018 (Table 3).

Table 3 –Total Fleet Cost Comparison: No EDSP vs. EDSP, Millions of $

Year	Capital & Operating		Fuel Costs		Emissions Costs		Total Fleet Cost	
	EDSP Benefit	Cumulative Benefit	EDSP Benefit	Cumulative Benefit	EDSP Benefit	Cumulative Benefit	EDSP Benefit	Cumulative Benefit
2010	-$10	-$10	$94	$94	$11	$11	$95	$95
2011	-$11	-$21	$149	$243	$16	$28	$154	$250
2012	-$11	-$31	$195	$437	$21	$49	$205	$455
2013	-$10	-$42	$251	$688	$26	$74	$266	$721
2014	-$4	-$46	$307	$995	$30	$104	$332	$1,053
2015	$2	-$43	$370	$1,365	$34	$138	$406	$1,459
2016	$13	-$31	$441	$1,806	$38	$177	$492	$1,952
2017	$25	-$6	$519	$2,325	$43	$220	$588	$2,539
2018	$41	$36	$604	$2,930	$48	$268	$694	$3,233
2019	$63	$98	$692	$3,622	$53	$321	$807	$4,041
2020	$78	$176	$787	$4,409	$58	$379	$924	$4,964
:								
2025	$248	$1,036	$1,361	$9,971	$91	$764	$1,700	$11,772
:								
2030	$635	$3,298	$2,192	$19,182	$145	$1,369	$2,972	$23,849

In addition, fuel cost savings associated with the implementation of the EDSP goals in the reference case scenario are projected to fully compensate for higher operating costs at the early stages of the plan implementation. Overall, the implementation of the EDSP is expected to generate cumulative benefits in excess of $23.8 billion from 2010 through 2030, on the basis of the comparison of bus fleet, fuel usage, and emissions cost associated with "No EDSP" and "EDSP Implementation" scenarios. Of these benefits, over $22 billion will be realized by the transit agencies in the form of capital, operating and fuel cost savings, with additional $1.4 billion worth of environmental benefits as a result of reduction in CO_2 and NOx emissions.

The comparison of total transit fleet costs associated with "No EDSP" and "EDSP Implementation" scenarios is presented graphically in Figure 4.

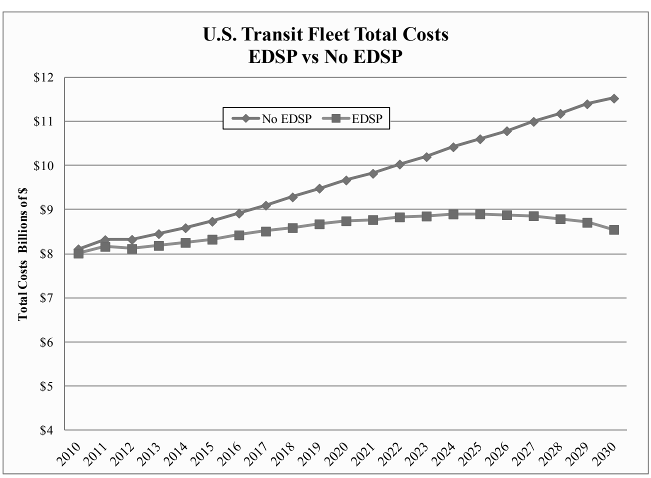

Figure 4 – Total Cost Comparison

6. Conclusions

The intensified global competition for limited energy sources, coupled with sharp oil price fluctuations and high dependence of the U.S. economy on the imported petroleum fuels, make energy security concerns more pressing than ever. In addition, the climate change impacts associated with GHG emissions from the combustion of fossil fuels, stimulates widespread interest in the energy alternatives, especially in the transportation sector, and public transportation in particular.

While there are several potential transportation technologies that, to a varying degree, may address the environmental and energy security concerns of traditional petrol-based fuels, the U.S. Federal Transit Administration (FTA) is considering to focus on the development of energy-efficient zero emissions electric drive transit systems as an ultimate alternative to diesel-powered public transportation vehicles.

FTA developed the Electric Drive Strategic Plan (EDSP) that provides for a wide range of activities for the development, demonstration, validation, and evaluation of the advanced electric drive transit technologies. The implementation of the EDSP is estimated to save 4.9 billion DGE of fuel and is projected to eliminate 98.7 thousand tons of NOx and 52.9 million tons of CO_2 in tailpipe emissions over the period of 2010 through 2030. These reductions in fuel consumption and GHG emissions are expected to produce substantial cost savings to the transit agencies, ranging from $15.9 to $30.0 billion, depending on the fuel price forecast, and generate environmental benefits valued at $1.4 billion over the 20-year period.

Actions taken to realize FTA's electric drive vision will have a meaningful impact on the energy future of the U.S., leading to significant environmental benefits and an improvement in the nation's economic competitiveness.

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Hydrogen Fuel Cell Transit Buses and Infrastructure – Contrasting Innovations

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ABSTRACT

Astounding technical progress has been made in fuel cell electric transit buses in a few short years driven by a well funded National Program with aggressive goals. The very prominent position that these transit buses play in the community attracts headlines but less media attention is focused on a vital element – the hydrogen fueling infrastructure. This paper presents information on CALSTART projects that have developed, delivered or are operating various configurations of fuel cell electric transit buses as a backdrop to describe the requirements and implementation of the hydrogen refuel infrastructure provided by two leading hydrogen suppliers – Air Products and Linde. Innovative approaches are described such as general-public/private-fleet installations, high-rate fueling and dual-fuel solutions as driven by the needs of the deployed fleets.

HYDROGEN FUEL CELL BUSES AND INFRASTRUCTURE

The need for transit hydrogen fuel infrastructure is a direct result of fuel cell electric buses funded by the Federal Transit Administration National Fuel Cell Bus Program (NFCBP), a $75,000,000 Research, Development and Demonstration program. The aggressive program goals have resulted in some dramatic technical achievements with more anticipated. Less focus was placed on infrastructure but the hydrogen suppliers provided tailored solutions to dispense fuel for the vehicles.

Three CALSTART NFCBP projects are used to compare and contrast the range of solutions driven by the fueling needs at the transit agencies. The AC Transit HyROAD project has a Linde solution for their fleet of twelve fuel cell buses. Smaller fleets or single bus fleets such as the American Fuel Cell Bus at SunLine Transit Agency and soon at the Chicago Transit Authority have unique implementations that represent ways to meet their lower fuel volume requirements. Finally, a unique Compound Hybrid fuel cell bus at San Francisco Municipal Transportation Agency has a “dual fuel” need. (Chandler, K. and Eudy, L. 2010)

FTA NATIONAL FUEL CELL BUS PROGRAM

Federal legislation funds the Federal Transit Administration “National Fuel Cell Bus Program” which is focused on commercializing fuel cell electric buses. The Congressional authorizing legislation was the Safe, Accountable, Flexible, Efficient, Transportation Equity Act - A Legacy for Users or SAFETEA-LU. To date over

$75,000,000 in federal funds matched by industry with another $75,000,000 has resulted in a total of over $150,000,000 investment in the technology. The projects and the teams that execute the projects are all competitively selected resulting in a well-balanced portfolio. Pictured in Figure 1 is the HyROAD fuel cell bus at AC Transit (upper right), the American Fuel Cell Bus at SunLine and soon at CTA (lower right), and the Compound Hybrid fuel cell bus. (Chandler, K. and Eudy, L. 2010)

Figure 1 Federal Transit Administration NFCBP and CALSTART Projects

The performance NFCBP objectives identified by the FTA are shown on the left in the Table 1 and the achievements to date are on the right in the table. For example,

Table 1 NFCB Program Objectives and Achievements to Date

PERFORMANCE OBJECTIVE	STATUS
Less than 5x cost of conventional bus	Cost reductions from > $3.0 M in 2006, to $2.0 to $2.5M. Plug-in battery-dominant bus << less.
Durability 4 - 6 year or 20,000 - 30,000 hours for the FCPS	11,000 hours+ achieved on FCS with durability warranties at 10,000 to 12,000 hours
Fuel economy 2x compared to commercial transit bus	Exceed 2x conventional bus, depends on route and bus design
Bus performance equal to or greater than equivalent commercial bus	Operate up to 19 hours/day, good availability, bus miles b/w road calls at 4,000 miles (<< than conventional); better acceleration, quiet operation, weight is still high
Exceed current emissions standards	Exceeds - zero emissions
Foster competition in FCB technologies	Multiple manufacturers and platforms demonstrating buses
Increase public acceptance for fuel cell bus technologies	Continued progress

the present generation fuel cells are over half the objective of 20,000 hours in durability and the next generation is expected to exceed 25,000 hours. The tested fuel-economy in operations, while highly dependent on duty cycle and terrain, has consistently exceeded 2x present diesel bus mileage on a gallon equivalent basis. Emissions are zero – the only emission is pure water vapor. The transportation fuel cell manufacturers that can compete for transit industry fuel cells have doubled and the supporting suppliers and supply chain has clearly expanded increasing the industry competitiveness.

HYDROGEN STATION SELECTION OVERVIEW

A critical defining parameter for a hydrogen station is the amount of hydrogen needed per day as determined by the size of the hydrogen bus fleet and the on-vehicle storage yielding the range necessary for daily operations. Table 2 provides an overview of hydrogen infrastructure issues and capacity for station types. The fleet size influences the number of dispensers and the fill-rate with a compatible fill receptacle, typically, to refuel the fleet in one 8-hour shift. Important also are the site parameters of availability, dimensions, and utilities. These elements with hydrogen source and the economics help to determine the basic station type. (Heydorn, E. C. 2008)

Table 2 Hydrogen Station Type and Typical Dispensing Capacity

- Hydrogen Capacity Needs
  - ✓Fleet Size
  - ✓Operations
  - ✓Bus Hydrogen System
  - ✓Fill Rate
  - ✓Bus Fill Receptacle
- Site Parameters
- Fuel Sourcing
- Economics

General Station Type	Typical Capacity (kg/day)
Liquid delivery *	1,000
Onsite reformation	100 –1000
Pipeline delivery	100
Onsite electrolysis*	30 –100
Mobile fueler *	50
Energy Station (CHP)	100 – 300

Some permanent stations have their hydrogen fuel delivered from a central production plant. Available delivery methods depend on the fleet capacity needs ranging from a pipeline, truck delivery as a liquid (LH_2) or a gas, and with a “fueler” which has storage and dispensing in a trailer unit. Other permanent facilities create hydrogen fuel on-site from local feedstock such as pipeline natural gas. Mobile fuelers and portable stations are relatively easy to move and have their own on-board fuel storage that must be replenished by periodic truck deliveries. Modular stations are ISO containers that do not have their own fuel source, requiring a separate fuel source. Some in the industry have even opted for something called an energy station. When there is a need and the right economics, a system can be integrated into facilities to supply reliable electricity on-site, provide for space heating and even hot water within the building while producing a "slipstream" or by-product of hydrogen that can be used for vehicle fuel.

The economics typically can be broken into a capital cost up front for site permitting, preparation, and equipment installation plus an operating cost. The operating cost can include equipment lease costs, energy costs to produce the hydrogen or a "molecule" cost for delivered hydrogen.

AC TRANSIT HyROAD EMERYVILLE STATION

AC Transit HyROAD Program is focused on accelerated operations of their fuel cell electric buses leading to major improvements in fuel cell durability and availability at rated performance. With a fleet of 12 buses operating up to two shifts per day even with an average mileage of 7.04 dge (diesel gallon equivalent) compared to 4.20 dge fuel economy for their standard forty foot diesel transit bus, the individual HyRoad fuel cell bus needs 24 to 28 kg of hydrogen per day. Accelerated operations with their fleet resulted in AC Transit and Linde opting for a liquid delivery station type with high-performance, fast-fill dispensing system. The Linde IC-50 ionic bus fueling system can fill the vehicle's hydrogen storage tank system with up to 30 kg of hydrogen at 350 Bar in 6 minutes. (Chandler, K. Eudy, L. 2010) (AC Transit Tour 2011) (LindeGas 2010), (Proton Energy Systems 2010)

The Emeryville hydrogen fueling station is a liquid hydrogen solution and began fueling buses in August 2011. The Emeryville dispensers are shown in Figure 2. An important attribute of the new fueling station is the capability to offer light duty vehicle fuel dispensing "outside the fence" for the general public, as shown in Figure 2. The bus fuel dispenser is "inside the fence at the Emeryville bus facility, on the left in Figure 2.

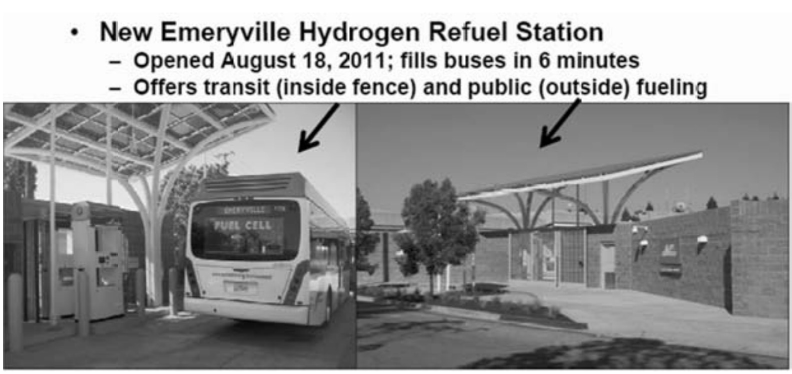

Figure 2 AC Transit Emeryville Refuel Station Dispensing Locations

Hydrogen is produced at a central production plant and delivered to the Emeryville station for storage and dispensing to the buses. In California, all central plants steam reform natural gas (often referred to as steam methane reformation or SMR). The hydrogen is then cooled to a liquid form and delivered in a tanker truck. The LH_2 station stores the liquid hydrogen in an insulated tank as shown in Figure 3. When needed, the station uses ambient air temperature to warm the fuel and to vaporize the H_2 into a gaseous state. Linde uses an ionic liquid to compress the gas, a process claimed to be more energy efficient and requiring less maintenance than a mechanical

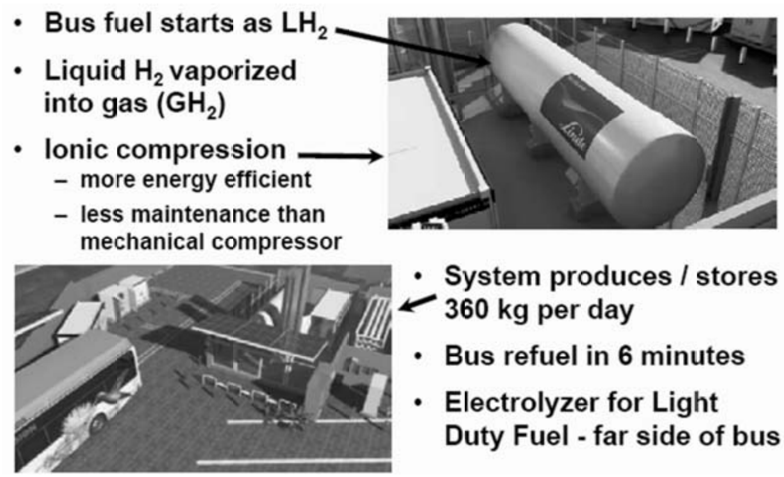

Figure 3 AC Transit Liquid H_2 Emeryville Station (AC Transit Tour 2011)

piston compressor. Using this method the system produces and stores 360 kg of H_2 per day. The system dispenses the hydrogen into the fuel tank on the buses providing a high-flow rate fill. This rate is crucial to widespread use of fuel cell technology in transit applications allowing for a large bus division to refuel in one shift with increased storage and an appropriate number of dispensers.

SMALLER FLEET SOLUTION FOR AMERICAN FUEL CELL BUS

The American Fuel Cell Bus (AFCB), shown in Figure 4 is a Buy-America compliant, fuel cell-powered demonstration bus featuring major technology advances and innovations. This fuel cell electric bus development project leverages the technical expertise of the best in class fuel cell system partners and a bus maker in the United States leading towards an extremely fuel efficient bus that may be able to realize a target cost of $1.5 million dollars or less than 5 times the cost of a conventional bus. The supplier team and SunLine are demonstrating a fuel cell bus efficiency that exceeds 7 miles /kg (or 8M/dge).

The AFCB has an improved version of a proton-exchange membrane 150 kW Ballard fuel cell and a BAE Systems improved electric motor drive subsystem, consisting of a power electronics suite that reduces weight, cost and noise. ElDorado National provided an advanced 40-foot bus chassis which has numerous bus-design improvements aimed at reducing weight, noise, and power consumption including the use of composite materials, aerodynamic streamlining of the bus body, improved air conditioning ducting, insulating windows, disc brakes, LED lighting, video cameras in place of side view windows, and reduced-friction tires.

Figure 4 SunLine Transit American Fuel Cell Bus

On-board hydrogen storage and an efficient power-plant provide greater than 350 miles range in the SunLine operations. A similar vehicle with additional improvements to the fuel cell is planned for use by the CTA. The following describes the equipment in use at SunLine and planned for support of the AFCB at Chicago.

SunLine Transit Agency has been able to test and demonstrate a variety of on-site hydrogen production methods through partner arrangements. This has included operation of electrolyzers powered by solar and wind from two different manufacturers and also natural gas reformers.

The reformer now on-line is a commercial Auto-Thermal Reformer (ATR) to demonstrate and test natural gas reforming. The vehicle fill-rates and cost of hydrogen production are key parameters. The hydrogen produced is compressed for storage prior to dispensing into the buses. Production is at a rate of 9 kg of H_2 per hour. The ATR unit has a good turn-down ratio allowing SunLine to operate the unit at 4.5 kg per hour which is sufficient to meet current demand but allow future support of a five fuel cell electric bus fleet. On-site storage of hydrogen is approximately 180 kg of hydrogen in nine ASME tubes and a tube trailer with another 16 ASME tubes. The hydrogen dispenser provides hydrogen to vehicles at a pressure up to 350 Bar.

The H_2 dispenser includes two hoses – one for fueling buses (low-rate fill) and one compatible with cars. The station is a member of the “California Hydrogen Highway” network. A card-lock system permits 24/7 access by the public to the hydrogen dispenser. SunLine is working with the California Department of Weights and Measures towards a dispenser meter approval for a metering capability for dispensing of hydrogen. Certification of the device will allow metered fuel sales of hydrogen – an important result for the widespread proliferation of public H_2 stations. (SunLine Transit Agency 2010)

The Chicago Transit Authority will also introduce and operate another American Fuel Cell Bus as one of the largest transit properties in the nation. By introducing and operating this fuel cell bus, the Regional Transportation Authority (RTA) will set the stage to deploy increasing volumes of fuel cell electric vehicles in the northeastern Illinois region. The project will facilitate the simultaneous development by Ballard of the "Next Generation Module" beyond the HD6 module, offering significant advances in durability, power density and fuel efficiency and supporting the commercialization of a fuel cell electric bus market at the target price of $1 million.

CTA was among the first in the nation to perform test trials on hydrogen fuel cell buses. An Air Products temporary storage and dispensing solution is planned for CTA to satisfy the need for a smaller footprint and supply for single bus fleets operation. Air Products has developed the HF150 Mobile Fueler as shown in Figure 5. It is modular with compression-less dispensing of up to 80-90 kg of hydrogen. The Air Products mobile refuel designs are compact, self contained units that require only a minimum in the way of utility service making them ideal for temporary dispensing.

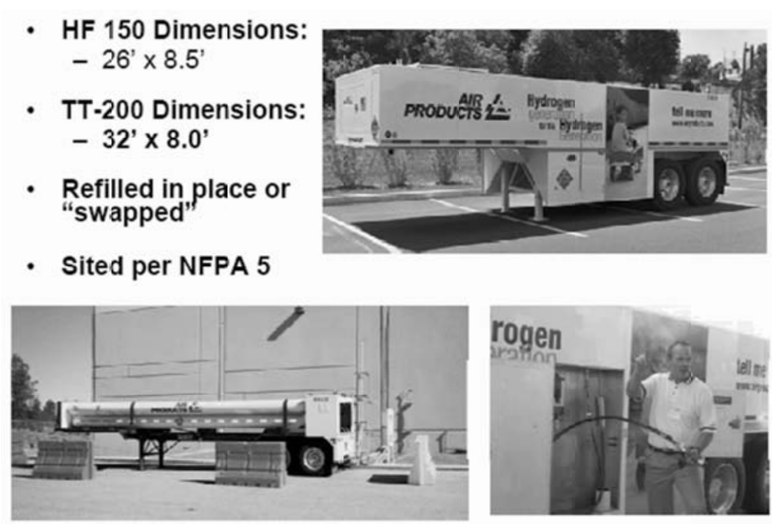

Figure 5 Planned CTA H_2 Infrastructure for Single Bus (Mittica, N. 2011)

SUPPORT OF DUAL-FUEL COMPOUND BUS ARCHITECTURE

The Compound Fuel Cell Hybrid Bus shown in Figure 6 is unique – this prototype electric bus is equipped with two power sources, a diesel-generator, and a small fuel cell system. This vehicle architecture is based on and leverages the strength of the growing hybrid bus industry, demonstrating a near-term alternative to electric buses powered strictly with fuel cells. Since thousands of hybrids are already in operation at transit agencies all over North America, the Compound Fuel Cell Hybrid concept can be potentially commercialized at a much lower vehicle cost than a full fuel cell electric bus. This product would provide transit agencies with a more fuel-efficient, low-emission bus procurement option that can reduce petroleum use and greenhouse gas emissions in a shorter timeframe and in larger numbers than likely possible in the next decade with hydrogen-only buses. (DOT/FTA 2011).

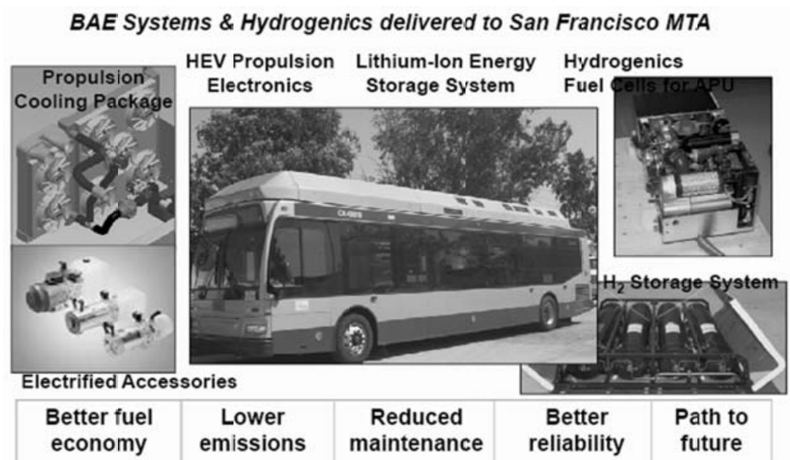

Figure 6 Compound Fuel Cell Hybrid Bus for SFMTA

Revenue service operations at the San Francisco Municipal Transportation Agency (SFMTA) will demonstrate and quantify these characteristics through comparison with baseline SFMTA series-architecture diesel-hybrid buses. A result of the dual power source architecture, the Compound Hybrid bus requires both diesel and hydrogen. The diesel is dispensed from a typical diesel fuel pump common in the transit industry. The Hydrogen dispenser solution is still being developed with options ranging from fueling at AC Transit's new Emeryville facility to a resident mobile fueler such as the Air Products mobile solution.

CONCLUSIONS

The hydrogen dispensing systems needed now by the transit industry are low volume systems. The largest North American fleet currently is 20 fuel cell electric buses and can range from one demonstrator to a "few" buses. The hydrogen industry fortunately has many options for low volume systems as well as potential high-volume systems. The key for transit operators is to select a starting point that is economical yet is compatible with the anticipated growth in their fleet of fuel cell electric buses. Scaling of the infrastructure has some logical start points and growth paths – for a single bus with a growth to a small fleet a tube trailer storage solution with a single dispenser is appropriate. For a larger initial fleet with a path to 10 or 20 bus fleet, liquid hydrogen storage and a plan for adding dispensers and more pumping and storage may be appropriate. Either path can be built out for even larger fleets by then installing on-site production equipment for hydrogen.

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Sustainability of Public Transport on the Rock Bed of Civil Infrastructure—Construction of Traffic Transit Management Centres by BMTC

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Bangalore Metropolitan Transport Corporation (BMTC) was incorporated into a separate entity after bifurcating from Karnataka State Road Transport Corporation (KSRTC) on Aug 1997. By 2012, BMTC leads by example in being the only Public Transport Corporation to ferry more than 4.5 million commuters' trips everyday within the city of Bangalore. The organization comprises a fleet of over 6100 buses covering an area encompassed with a radius of 40.4 kilometers from the city centre. In a day BMTC operates on 585 city and 1858 sub urban routes, running 13.5 lakh kilometers and making 78750 trips. BMTC has a 32,729 strong labour force to carry out different activities of BMTC bus operations. BMTC has 37 Depots, two Central Work Shops, 6major bus stations and 41 minor bus stations and 10 passenger amenities centres popularly known as the Traffic Transit Management Centres. BMTC serve the transport needs of urban and sub-urban population in and around Bangalore. And, despite the differentiated base of the commuting population, BMTC reaches far and wide, in every nook and corner of the city making public transport an attractive travel choice for everyone. BMTC's strong hold in the area of public transportation in Bangalore is a testimony to its adoption of sound Management, HR, Quality and Environmental policies. The corporation also strives to bring about increased passenger comfort by integrating Intelligent Transport Systems (ITS) and Passenger Information system (PIS) in its daily operations. This helps to monitor its services better and provide quality services. Public feedback is also an important input in BMTC operations; a state of the art control centre is envisioned for the near future which will be a one point contact for addressing customer queries and feedback. BMTC caters to the transportation needs of Bangalore by offering quality bus services though it is grown in radial direction.

BMTC has adopted several reformatory measures to transform working of the organization to a professionally administered entity with an objective of providing a sustainable public transport system to enhance the welfare of the citizens. BMTC's focus is on ***moving people*** in Bangalore city, a fastest growing city in Asia and fifth largest in India. The reformatory measures adopted by the BMTC are structural reforms in the organization, strengthening of infrastructure, fleet modernization, augmentation of services, revenue mobilization measures, use of information and communication technology for improvement in systems and processes, extensive use of Information technology for revenue generation and other sectors, cost control measures, transparency in HR policies and recruitments, involvement in public-private partnerships, etc. BMTC has achieved it in providing efficient, affordable, safe, comfortable and environmental friendly urban transport. It has taken cohesive decisions and implemented them in right earnestness keeping low fare structures, attending to social obligations, and taken steps to improve efficiency. BMTC has pooled all its resources, ensured optimum usage of each of its material and human resources. BMTC has also convinced the government in taking appropriate policy related decisions such as reduction in taxation, fare policies, financial support through reimbursing concession services extended to students and other categories of social obligation. Karnataka Government was equally supportive to BMTC efforts and has encouraged in its spectrum of activities in providing a sustainable transport to the people of Bruht Bangalore. The efforts initiated by the corporation have gained confidence of its employees and common public. Through the committed leadership at al levels in the organization, it was able to optimize the strengths, competencies and efficiencies. BMTC has adopted innovative programs and initiatives in order to improve ACCESS to people with a vision of more effective and responsive public transport system of the future for the city

Govt. of India launched Jawaharlal Nehru National Urban Renewal Mission (JnNURM), to address and improve urban infrastructure in different cities of India. Bangalore is one among the 65 cities identified as being eligible for JnNURM assistance. In pursuant to this, BMTC formulated a "Vision Plan" with an outlay of INRs. 30,000 Million spread over five years emphasizing development of urban transport infrastructure. The construction of TTMCs is one among them

Traffic Transit Management Centres focus on:

1) Enhancing efficiency of public transport through integration of different modes of transport. 2) Address the lion share of public transport needs of the Bangalore City through BMTC. 3) Provide innovative financing by leasing out commercial space in the TTMCs. 4) Provide passenger amenities.

The main objective of these TTMCs is to provide Urban Transport Infrastructure with several amenities under one roof and encourage the following.

1. To meet some of the objectives of the Indian National Urban Transport Policy (NUTP).
2. To provide an integrated transport facility with adequate amenities and conveniences to cater to the requirements of all users group.
3. To minimize / reduce further congestion on main roads through properly co-ordinate traffic movement.
4. To ensure smooth flow of traffic to and from the terminal so that there is no congestion / disturbance caused to the traffic along the main road.
5. Minimum / no conflict between various traffic types – passengers, buses, private vehicles and other road users to

achieve minimum passenger and vehicle processing time.

6. To encourage use of public transport and provide first-last mile connectivity through provision of park and ride facilities in the proposed bus terminal.
7. To facilitate commuters to park their private vehicles & access to public modes of Mass Transport

BMTC has formulated unique innovative Traffic Transit Management Center (TTMC) projects as part of development of urban civil transport infrastructure to demonstrate the possible best practices in sustainable transport facility and first in the country, where in the public can come from their places in the public transport mode and make use of all the public amenities provided in TTMCs and again go back to their destinations. They get all their daily requirements at single place. This will help the city to minimize congestion and also reduce the pollution hazards, thus they will be eco friendly. This system can be integrated with other modes of transportation systems like metro, mono & express rail corridors also.

TTMCs contain the following civil infrastructure components.

a. Bus Depot

To provide maintenance & Parking facilities for Buses,
Rest Rooms for Crew & staff.

b. Bus Terminal

State of the art bus terminus and passenger facility with assured safety to passengers

c. Integrated passenger amenities:

Basic Health, Financial, Transport, House-hold & Service related facilities

d. Park & Ride Facilities

TTMCs provide 34 public amenities / services to the common public,

<u>A: Minimum Basic facilities:</u>

1) Clean drinking water facility.
2) Clean hygienic Toilet facility.
3) Comfortable rest places for the passengers.
4) Multi-level 2-wheeler and 4- wheeler parking facility.
5) Police out post for security and safety of passengers.

B: Health related facilities:

6) Public health centre.
7) 24 Hours Chemist Shop.
8) Health Club.

C: Services related facilities:

9) Post office counter.
10) Electricity bill payment counter.

10) Water Bill payment counter.
11) Telephone Bill Payment counter.
12) BBMP counter.
13) Counter for payment / submission of Income Tax returns
14) Counter for payment of Excise and Commercial Tax returns
15) A cyber café.
16) Counter with public telephone facility and a Xerox centre.

D: Financial related facilities:

18) Banks.
19) ATM counters.
20) Foreign Exchange Bureau.

E: Transport related facilities:

21) Bus station for bus connectivity to different places.
22) KSRTC bus reservation counters.
23) Railway reservation counters.
24) Air booking / reservation counter.
25) Counter for flight check-in facility for domestic Airlines.
26) Counter for courier services for both domestic and overseas.
27) Counter for Taxi services.
28) Counter for Karnataka State Tourism.
29) Counter for Tourism outside the State. 30)

F: House Hold Requirement facilities:

31) Food Court.
32) Departmental Stores.
33) Book Stores.
34) Gift & Fancy Stores.
35) Crèche for Children.

BMTC identified 10 places to construct the TTMCs, as a development plan of Transport Infrastructure under JnNURM. Central Sanctioning & Monitoring Committee (CSMC) under JnNURM sanctioned these 10 TTMCs projects for an outlay of Rs.479 crore. These TTMCs Projects are executed by BMTC through JnNURM funding mechanism, i.e. GoI-35% (grant), Go K-15% (grant) & BMTC-50%.

All TTMCs were operational by 4-12-2011 which are located in the prime area of the Bangalore city like Jayanagar, Sahnthinagar, Vijayanagar, Yashawanthapur, Koramangala, ITPL, Bannerug hatta, Domlur, Kengeriand Banashankari BMTC has 284,620 sqm built up area,2,55,000 sqm can be used for the commercial purpose and will generate the revenue of INRs 240 Million per annum which is a perennial source of income.

Table 01

The table showing the important details of the project like, place, cost, commencement of project, completion of project and funding details

Sl. no	Project name	Approved cost (Rs in Lakh) lakh*)	Tender inviting date	Work Started	Inauguration date	GOI (35%)	GOK (15%)	BMTC (50%)
1	Jayanagar	889.58	16/01/2007	22/02/2007	31/08/200 9	311.35	133.44	845
2	Shanthinagar	8467.96	16/01/2008	31/07/2008	23/09/201 0	2963.78	1270.1 9	6488
3	Koramangala	5058.06	16/01/2008	06/08/2008	17/02/201 1	1770.32	758.71	4536
4	Itpl	2655.63	16/01/2008	06/08/2008	11/01/201	929.47	398.34	2383
5	Vijayanagar	3812.42	16/01/2008	31/07/2008	05/03/201 1	1334.34	571.86	3426
6	Kengeri	2112.66	16/01/2008	25/06/2008	10/07/201 0	739.43	316.9	4113
7	Banashankari	2223.51	16/01/2008	18/11/2008	4/12/2011	778.22	333.53	1999
8	Yeshwanthapu r	6131.93	16/01/2008	07/08/2008	24/05/201 1	2146.17	919.79	4884
9	Domlur	1555	6/01/2008	31/03/2009	26/02/201 1	544.25	233.25	980
1 0	Bannerghatta	392.6	6/01/2008	31/03/2010	29/08/201 0	137.41	58.89	353
	Total	**33299.35**				**11654.75**	**4994.9**	**29907**

One Lakh is 100000

Situation Before the initiative began

This is a new initiative taken up by BMTC in order to make the public transport comfortable by implementing the civil engineering technology. The Traffic Transit Management Centers emerged as the panacea for the passenger worries and devoid transport infrastructure for the Public transport system. There was no platform for the integration of the different modes of transport.

ESTABLISHMENT OF PRIORITIES

BMTC formulated unique innovative Traffic Transit Management Center (TTMC) projects as part of development of urban transport infrastructure to demonstrate the possible best practices in sustainable transport, where in the public can come from their houses in the personal /public transport mode and make use of all the public amenities provided in TTMCs and again go back to their destinations. They get all their daily requirements at single place. This will help the city to minimize congestion and also reduce the pollution hazards, thus they will be eco friendly. This system can be integrated with other modes of transportation systems like metro, mono & express rail corridors also.

MOBILISATION OF RESOURCES

The Detailed Project Reports (DPRs) were prepared for 10 TTMCs through consultants and sent to GoI through Karnataka Urban Infrastructure Development Finance Corporation (State Nodal Agency) for appraisal and approval. TTMCs Projects are executed by BMTC through JnNURM funding mechanism, i.e. GoI-35% (grant), Go K-15% (grant) & BMTC-50%. Upon completion of the project, O & M will be under PPP for medium to long term.

Table -02 Funding Details Rs in Crore *

Sl.No.	Project Name	Sanctioned Cost at CSMC Delhi	Cost (With Tende	Share of GOI & GOK BMTC		Completion Date
1	Jayanagar	8.90	14.80	4.45	10.35	Aug-09
2	Kengeri	21.13	40.00	10.57	29.43	Jun-10
3	Bannerghatta	3.92	5.50	1.96	3.54	Jun-10
4	Shanthinagar	84.68	108.5	42.34	66.16	Aug-10
5	Vijayanagar	38.12	58.10	19.06	39.04	Aug-10
6	Koramangala	50.58	71.90	25.29	46.61	Sep-10
7	Domlur	15.50	19.35	7.75	11.60	Sep-10
8	Whitefield	26.56	37.30	13.28	24.02	Oct-10
9	Banashankari	22.24	32.25	11.12	21.13	Oct-10
10	Yeshwanthpur	61.32	91.90	30.66	61.24	Nov-10
	Total (In Crore)	332.95	479.6	166.48	313.12	

One Crore is 10 mn 10Million GoI : Govern ment of India , GoK :Govern ment of K arnataka

PROCESS

The construction of TTMC work was entrusted to the agencies by floating Global tenders in which reputed companies were participated and with complete transparency.

The construction work of TTMCs was taken up in the Central Business Districts area, the supply of construction material was a challenging task, and the HTV and RMV were used only during night time to supply the materials without hampering the smooth movement of traffic in consultation with police and local bodies.

These buildings were planned at the places where already the bus stations and maintenance depots were in operations, the construction work was taken up in a phased manner without disturbing much the operation and maintenance. The Commuters Comfort Task Force committee and the Commuter Advisory & Facilitation Committee were consulted. These committees are represented by the Resident Welfare Association & NGOs involved in the consumer movement. The National Building Code norms were completely adhered to .There were problems in the site areas like water logging, old quarries and subsoil weak, the precautionary measures were taken to address the problems.

It is interesting to note that no explosives were used in digging the area, using the pneumatic tools and the controlled blasting technique was used in this regard. The regulatory norms fixed by the local bodies were completely adhered to and the cooperation from these bodies were obtained in completing the projects.

The hallmark of this project initiative was professional approach. M/s IDEK (Infrastructure Development Enterprises of Karnataka was appointed as the project consultant for the preparation of Detailed Project Reports and project management services. M/s Civil Aid Techno Clinic Pvt Ltd a unit of Tar Steel Research Foundation of India (TRFI) was appointed as third party to assess the construction work of the buildings. Bangalore Metropolitan Transport Corporation established the quality control laboratory at project sites and carried out the quality audit then and there and ensured the quality. The random quality samples were selected and were sent for quality checking at M/s Civil Aid Techno Clinic Pvt Ltd.

From BMTC the Managing Director & C E O along with the Functional Directors and Heads of the Department constantly visited the work spots and supervised construction work. The issues related to construction were settled as and when they arose on the spot.

Many a time the Hon’ble Minister for Transport visited the work spots and expressed the happiness over the construction work.

It is totally the professional approach to the construction work keeping the interest of all the stake holders.

RESULTS ACHIEVED

The following facilities and amenities are provided for the commuters.

Bus Terminal Amenities	**Bus Maintenance Depot**	**Passenger**
Bus Bays	Maintenance Bays	ATMs
Platforms	Washing Platform	Health Centre
Seating & Lighting	Bus Parking	Shopping
	Public Conveniences	Services & Utilities
		Food Court
	Fuel Filling Station	Internet Café
	Amenities for the crew	Hygienic Toilets
		Rest Rooms
		Bangalore One

Table -03, Details of Civil Transport Infrastructure in TTMCs

Sl.	**Project Name**	**Site Area**	**Total built up area**	**Vehicle Parking**	
				2 W	**4 W**
1	Jayanagar	3,700m2	9,267m2	50	60
2	Kengeri	17,759m2	23,964m2	1200	200
3	Bannerghatta	8,093m2	1,677m2	-	-
4	Shanthinagar	38,162m2	57,582m2	525	742
5	Vijayanagar	15,581m2	45,200m2	250	750
6	Koramangala	19,618m2	37,596m2	225	382
7	Domlur	5,424m2	8,166m2	150	250
8	Whitefield	12,215m2	28,733m2	80	425
9	Banashankari	7,756m2	15,360m2	120	256
10	Yeshwanthapur	14,940m2	43,173m2	200	650
	Total	**1,43,248m2**	**2,70,718 m2**	**2800**	**3715**

The projects were completed well within the time and were made operational .The Hon’ble Minister for urban development Govt of India inaugurated a few projects. The most benefited are the passengers who were waiting for the buses on the road were made to wait in the modern bus station with the above said facilities. This reduced the traffic congestion, accidents and anxiety among the passengers due to lack of transport infrastructure. There was creation of additional revenue to the BMTC which is perennial in nature and make good of the marginal loss caused due to increase in the cost of operation. The economic activities became brisk in and around the TTMC areas.

SUSTAINABILITY

The Traffic Transit Management Centers are the passenger amenity centers established for the benefits of passengers under this project. These are also known as the elements of transport infrastructure. The sustainability is achieved in the following areas

Financial: The TTMCs are the role models for the transport infrastructure, under which the passengers gets maximum benefits related to public transport. These centres emerge as the important transport hubs to increase the ridership for the BMTC and are the perennial source of revenue helping in the financial sustainability of the BMTC. The park and ride facilities encouraged the people to use the public transport. The opening of various Government and corporate offices brought the services to the door step of the people.

Social and Economical: The centres are the meeting places of all category of people who wish to travel by public transport. The economic activities became brisk by the emergence of these centres. The easy accessibility of public transport helped people to access for modern facilities. The direct connectivity to various economic , educational and service centres from these centres. There by encouraged to improve the standard of living of the people. The establishment of departmental stores and entertainment centres in these buildings became the socio economic centres.

Cultural: These centres became the meeting centres for people of different cultures. The clean and systematic bus stations encouraged people to mend themselves to suit the situation. The aesthetic look of the building, seating arrangements, passenger information system , spic and span of the premises, improved signage and disciplined arrival and departure platforms heled to avoid confusion in availing the public transport service. The multilevel park and ride facilities are the much appreciated everywhere.

Environmental: The main objective of this project is to assist in the environmental conservation by way of reducing the personal mode of vehicles thereby save the petroleum products for the nation. These buildings are constructed with the plan of using natural lighting, rain water harvesting is made as compulsory in constructing these buildings. The beautiful landscape and garden places are provided to get environment friendly appearance. The bus maintenance depots are established in the basement area to avoid dead kms and save the energy.

LESSONS LEARNED

The following are the lessons learnt from this project.

1. **Development of civil transport infrastructure is a must for operating public transport**

   The infrastructure is the backbone of the public transport system. This must be developed with the considerations of utility, spaciousness and commuter comforts. The big space will encourage making the place as the important hub for public transport. The spacious buildings can easily accommodate passenger requirements and make public transport a comfortable one.

2. **There is a need for integration of different modes of transport**

   The TTMCs under this project are the multimodal hubs. The persons having two wheelers and four wheelers can park their vehicles and travel by public transport. There is a provision for the other modes of public transport like taxis, autorikhsaw, buses for outside city services to railway stations and airport are a few among them.

3. **Improved civil infrastructure will improve the ridership**

   The improvement in bus bays ,lighting ,waiting lounge, seating, queue system, controlled accessibility, signage, passenger information system, establishment of service provides kiosks, providing entertainment and commercial husband park &ride facilities are the required services in the public transport places. These services will have the impact on the ridership in public transport.

4. **Transparency is a must public sector enterprises.**

   BMTC adopted transparent systems in establishing the TTMCs from the beginning. The agencies were selected through the transparent ways and were constantly supervised in implementing the projects on time. This helped in speedy completion of the projects well in time.

5. **Civil infrastructure help for sustainable means of revenue sources**.

   Normally, the public transport corporations get the revenue from the sale of tickets and passenger passes which is known as the traffic revenue. There is a revenue source other than the traffic revenue which is known as the commercial revenue, this is realized through the letting out the building space available with the public transport corporations. The construction of Traffic Transit Management Centres are having the 1,43,248 m2 site area,2,70,718 m2 built up area and parking for 2800 two wheelers and 3715 four wheelers. The total expected revenue from these buildings is more than INR 48 crore per annum. This will help BMTC to make good the loss caused due to increase in the fuel prices.

Conclusion

The construction of Traffic Transit Management Centres is a pioneering work of BMTC in the field of transport infrastructure development under the joint funding of Jn NURM by Government of India and Government of Karnataka. The Officers working in Traffic, Accounts and Civil Engineering department of BMTC did a commendable job in finishing the construction work of these centres on time and this experience was shared with other professionals visited BMTC.

The Government of India with this experience extended the schemes elsewhere in the country. The neighboring transport corporations of Karnataka got funding under various Karnataka state Government schemes for transport infrastructure development schemes. The Officers from other state transport corporations of India visited BMTC to share the idea of developing the transport infrastructure in their corporations. The representatives of World Bank, ADB and academic institutions visited BMTC to share the knowledge to implement the same in their places.

The State and Central Governments can take up such projects to popularize the public transport in Metropolitan and two tier cities.

Assessing the Sustainability of Public Transport in A Developing Country – Case Study of Accra Ghana

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ABSTRACT

This paper documents an assessment of public transport projects in Accra, Ghana based on local sustainability criteria. The assessment is conducted using a framework suggested for screening urban transport projects in developing countries according to criteria developed to reflect local concerns for sustainability. The framework integrates indigenous (i.e., local) and scientific knowledge to predict how specific projects might support sustainable transport development. It is a participatory process that integrates input from system users and providers to produce a term defined as the Localized Sustainability Score (LSS). The LSS of each candidate project is used to produce a relative ranking of potential projects as part of a screening process by which candidate projects can be prioritized or selected for further consideration. It also provides a mechanism to engage system users and document their input.

INTRODUCTION

The application of indigenous knowledge to sustainable practices in developing countries is well documented (Agrawal 1995; World Bank 1998; Briggs 2005; Rist and Dahdouh-Guebas 2006). This paper discusses an assessment of public transport projects in Accra, Ghana based on local sustainability criteria. The assessment is conducted using a framework suggested for screening urban transport projects in developing countries according to criteria that is developed to reflect local concerns for sustainability (Tefe 2012). The framework is based on the integration of indigenous (i.e., local) and scientific knowledge of how specific projects might support sustainable transport development. It is a participatory process that integrates input from system users and providers to produce a term defined as the Localized Sustainability Score (LSS). The LSS of each candidate project can then be used to produce a relative ranking of potential projects as part of a screening process by which candidate projects can be prioritized and selected for further consideration. It also provides a mechanism to engage system users and document their input.

BACKGROUND

Accra is the capital of the West-African nation of Ghana. Accra and its environs, referred to as the Greater Accra Metropolitan Area (GAMA) had a 2010 population of 2.3 million (CIA 2011). The population is projected to exceed 4 million by 2013 (DHV and MDC 2005b). With regard to transport, there were some 181,000 cars estimated to be operating in Accra in 2004 (CIA 2011). The remainder of urban transport needs is served by a mixture of public transport, taxis non-motorized transport (NMT) and private cars. Public transport in Accra comprises fixed route public buses (Metro Mass Transit) and privately operated fixed route mini-buses (called tro-tros) operated by one of two main private operator unions (DHV and MDC 2005a; DHV and MDC 2005b). In Accra, public transport trips account for about 70% of urban vehicular trips yet constitute only about 25% of the traffic mix (World Bank 2006). Only 20% of the system user respondents have personal cars and 24% come from households where someone owns a car that is often not available for the respondent's use. Meanwhile 56% of the respondents do not have access to any personal car.

Accra was chosen as a case study as the researchers had access to two recent large-scale urban transport studies conducted using conventional (i.e., cost-benefit) transport planning approaches to rank candidate projects. The results of these studies were compared with the results of the proposed screening process. Specifically, a Localized Sustainability Score (LSS) was developed for five actual projects from Accra using the proposed framework. Two of the projects are major roadway projects, two are Bus Rapid Transit (BRT) projects and the fifth is an area-wide NMT project that was completed in 2000.

Table 1. Description Of Accra Projects Used In Case Study

Designation	Project Name	Scope	Source
P1	Motorway Extension	The road is a 13.5km major bypass, located close to the periphery, yet passing through a built up area. The road currently has a single carriageway, which is to be upgraded to a 4-lane motorway with full access control. The road is an important link between two major corridors, and experiences heavy congestion, but the upgrading met lots of resistance due to the massive property impact of the project. The conventional method ranked this project in 1st position for immediate implementation.	DHV and MDC. (2005a).
P2	Lashibi Road	It is a 7.6km East-West corridor with single carriageway, to be upgraded to a dual carriageway. It is an important link between two suburbs, passing through mostly undeveloped land and expected to have less property impact. It was selected because it was ranked 4th for deferred implementation in the conventional method.	DHV and MDC. (2005a).
P3	Winneba Road BRT	The existing 16km road is a dual carriageway with three lanes per direction. Some short 2-lane sections are to be widened to three lanes to provide a dedicated bus lane per direction. The road way is a major commuter route into the central business district (CBD), linking the Motorway extension at the other end. Selected because it was ranked in 1st position in the conventional evaluation.	DHV and MDC. (2005b).
P4	Nima - CBD NMT	This is an 14km long non-motorized transport (NMT) arterial that links a notable cycling community to the CBD. It is the first known NMT arterial to be constructed in the city, so is often used as a reference for NMT infrastructure. It was selected in this study to add variety and completeness to the evaluated projects.	

P5	Accra-Tema Beach Road BRT	The roadway is significantly an 18km single carriageway to be upgraded to provide an extra lane per direction for use as exclusive bus lane. It is an important corridor that links the CBD to the important harbor city of Tema. Project will have considerable property impact and is selected because it was ranked 4th in the conventional method for deferred implementation.	DHV and MDC. (2005b).

DATA COLLECTION

Transport system users and providers in Accra were engaged via a participatory process to elicit indigenous needs, perceptions and opinions regarding the local transport system. In the case of the system providers, professional opinion (based on scientific knowledge) was documented with regard to how the five case study projects, described in Table 1, might best serve sustainable transport criteria and sub-criteria identified as important to the system users. The Department of Urban Roads is the execution agency for these projects. Table 2 shows the sustainability criteria and sustainable urban transport sub-criteria identified/developed in conjunction with local system users and providers.

Table 2. Summary of Selected Criteria and Sub-Criteria

Sustainability Criteria	Sustainable Urban Transport Sub-criteria
Economic	Job Access, Market Access, Education Access, Reliability, Affordability. Roadside Commerce, Safety, NMT, Public Transport Quality
Social	Healthcare Access, Activity Access, Personal Security, Stress Free Travel, Neighborhood Preservation
Environmental	Air pollution, Noise Pollution

Structured questionnaires were administered to a total of 305 system users to identify local sustainable transport issues and their relative importance among system users. A separate set of questionnaires was administered to 32 system providers. The system providers were selected from among 12 stakeholder agencies in the transport sector in Accra, while the system users were randomly selected at various locations throughout the city. The questions were administered at three levels. Level I questions involved qualitative weightings for a set of three sustainability criteria, economic, social and environmental. The Level I questions were administered as pairwise comparisons to both system users and providers. Initial tests of the surveys indicated that system users (i.e., general population) found pairwise comparisons difficult when more than three total choices were available. The Level II questions employed a Likert Scale that allowed the system users to convey how important each of sixteen sustainable transport sub-criteria was to them. The Level III questions were also pairwise comparisons. In this case, the comparisons were among the relative perceived impacts of five transport projects across sixteen sub-criteria. This resulted in 100 questions and required a relatively sophisticated knowledge of the projects and their overall transport impacts on the traveling public in Accra. As such, the Level III questions were only administered to system providers. All the different weightings were analyzed together using a modified Analytic Hierarchy Process (AHP) (Saaty 1980) to generate a relative prioritized score (LSS). Samples of the questions for each level are given in Table 3 and Figure 1 is a diagram of the modified AHP process used to develop the LSS.

Table 3. Sample Questions

Level	Type	Sample Question(s)	Purpose
I	Pairwise Comparison	Considering how transport affects economic activities and social issues, which is more important to your daily life? • Economic activities are much more important • Economic activities are more important • They are equally important • Social issues are more important • Social issues are extremely much more important	This is a typical question asked to elicit relative comparison among the three primary areas of sustainability: economic, social and environmental. The questions were answered by both system users and providers.
II	Likert Scale	How important to your daily life do you consider traveling to your place of work with ease? 1. Unimportant: I do not travel to and from work. 2. Somewhat unimportant: I have many other places to go in addition to work. 3. Important: Traveling to and from work is only one of many trips I make each day. 4. Somewhat important: It is also quite important for me to travel for other reasons. 5. Very important: To go to work is the primary reason I travel.	The questions in this section reflect the needs, priorities and perceptions of system users.
III	Pairwise Comparison	Which local transport project would you consider better for improving overall transport system quality? • Motorway Extension project is much better • Motorway Extension project is better. • Same project impacts. • Winneba Road BRT project is better. • Winneba Road BRT project is much better.	These questions allowed system providers to compare potential impacts of the case study projects using their knowledge of local transport conditions and their professional/technical understanding of each project.

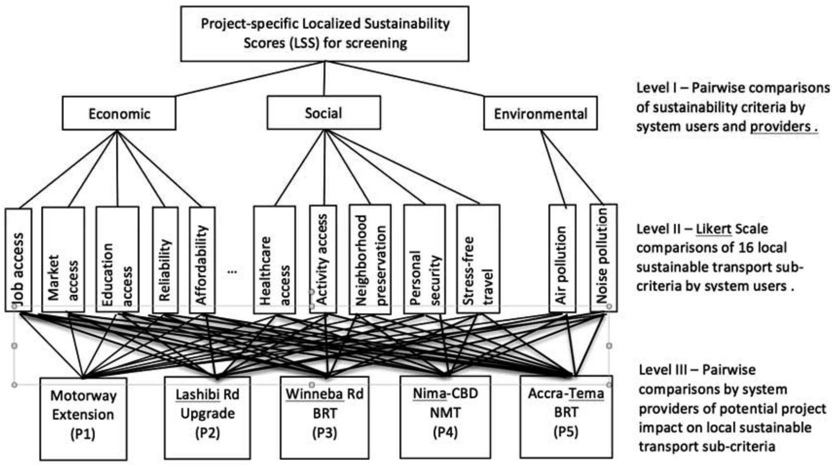

Figure 1. Localized Sustainability Score (LSS) Framework

RESULTS

Prior to developing the relative ranking of the five Accra case study projects, an analysis of the public transport-related characteristics of the participatory process was summarized. While no specific mode split data were collected within the LSS framework, survey questions were included in attempt to ascertain the relative importance of public transport to the respondents. Figure 2 shows how the 305 system user respondents rated the importance of having a quality public transport system in Accra.

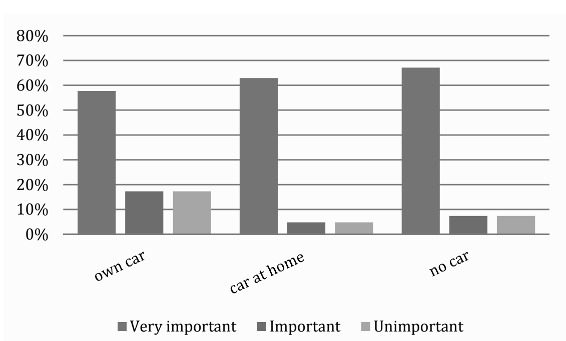

Figure 2. Public Transport Importance Among Surveyed System Users.

The significance of public transport in a developing country cannot be overemphasized. As shown in Figure 2, over 55% of all respondents considered public transport to be very important, irrespective of car ownership. Thus public transport is an important mode in Accra even as automobile ownership increases. Figure 3 shows the relative importance of an efficient public transport among the income level and employment status characteristics of the surveyed system users.

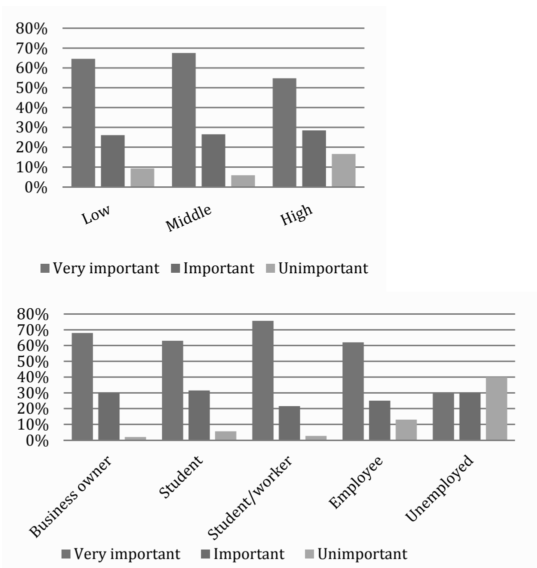

Figure 3. Income, employments status and public transport importance.

As shown in Figure 3, over 50% of all income groups considered public transport to be very important. The middle income group attached the most significance to public transport, while 17% of the high income respondents considered public transport to be unimportant. In the employment category, the group that attached the most significance to public transport is the workers who also attend school as part-time students. This is a group of people to whom time is of great importance because they have to shuttle between job and evening classes within short time intervals. Most of these workers do not have personal automobile and are dependent on public transport. Hence public transport is of great economic value to this group of workers. The unemployed seemed to have the least value for an efficient public transport as only 30% of this group considered public transport as very important, compared to over 60% for all the other employment categories. Interestingly, some 40% of the unemployed considered public transport to be unimportant. Such a result either reflects a lack of mobility (or demand) on the part of the unemployed or that their travel behavior is less time constrained than those adhering to work-related schedules.

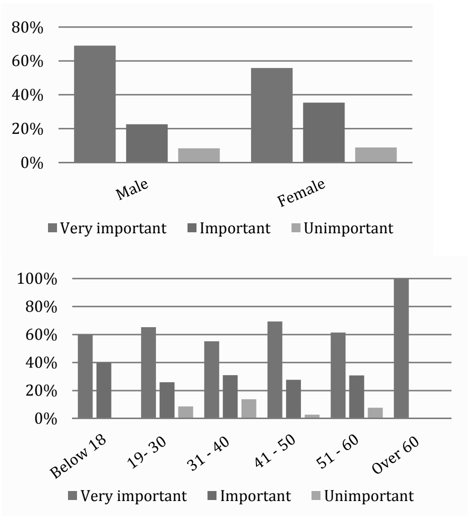

Figure 4. Gender, age and public transport importance.

Figure 4 shows the relative importance of public transport with respect to the age and gender of the respondents. About 70% of male respondents considered public transport to be very important as compared to 55% of women respondents. Perhaps more of the males are employed in the formal sector with strict time constraints and more women are employed in the informal sector with more flexibility in their travel needs. Less than 10% of each category considered public transport to be unimportant. This implies that public transport has some importance to more than 90% of both males and females and any difference may only be a function of external factors (job schedules, etc.).

All (100%) respondents over 60 years considered public transport to be very important whereas only an average of 60% of respondents below the age of 60 considered public transport to be very important. This could be another reflection of the transport system in Accra, where supply is much lower than demand, so commuters struggle to board the few available vehicles. The result is that commuting becomes more stressful for the elderly especially those above 60 years of age. So they place more value on having an efficient public transport system than any other age group.

Table 4 summarizes the LSS computed for the five case study projects. The values were derived using the AHP, through pairwise comparisons, to reflect the importance of particular sustainability sub-criteria to system users and how well the system providers judged that sub-criteria would be served by each individual project. The weightings start by comparing the criteria with respect to the goal to develop a priority list (in the range of 0-1). The process is repeated for the sub-criteria and then the projects, deriving priorities for each level. The values in Table 4 represent the product of the criteria, sub-criteria and project priorities and the sum of these values for an individual project (i.e., column sum) is the LSS for that project. A higher LSS indicates a project that better meets the local sustainability criteria.

Table 4. Summary of LSS Scorings for Candidate Projects

Criteria	**Sub-Criteria**	**Motorway Extension Project (P1)**	**Lashibi Road Project (P2)**	**Winneba Road BRT (P3)**	**Nima-CBD NMT Project (P4)**	**Accra-Tema Beach Road BRT (P5)**
Economic (0.42)	Job Access (.12)	0.013	0.006	0.012	0.005	0.014
	Market Access (.08)	0.010	0.005	0.010	0.004	0.011
	Education Access (.12)	0.013	0.006	0.013	0.005	0.014
	Reliability (.12)	0.012	0.008	0.013	0.006	0.010
	Affordability (.13)	0.006	0.005	0.016	0.015	0.008
	Roadside Commerce (.06)	0.004	0.004	0.005	0.004	0.006
	Safety (.13)	0.010	0.008	0.012	0.015	0.012
	NMT (.09)	0.005	0.006	0.008	0.015	0.007
	Public Transport (.13)	0.011	0.009	0.017	0.004	0.015
Social (0.26)	Healthcare Access (.21)	0.014	0.007	0.013	0.006	0.015
	Activity Access (.21)	0.014	0.007	0.013	0.006	0.015
	Neighborhood Preservation (.22)	0.006	0.007	0.009	0.007	0.010
	Personal Security (.22)	0.013	0.008	0.015	0.007	0.014
	Stress Free Travel (.15)	0.013	0.008	0.015	0.007	0.014
Environmental (0.32)	Air Pollution (.55)	0.028	0.019	0.040	0.057	0.036
	Noise Pollution (.45)	0.022	0.015	0.032	0.046	0.029
	LSS	**0.194**	**0.129**	**0.245**	**0.208**	**0.229**
	Ranking	4	5	1	3	2

Table 4 indicates that the public transport projects Winneba Road BRT and Tema Beach Road BRT projects were scored highest, receiving the LSS of 0.245 and 0.229, respectively. This reflects the significance of public transport to system users and the system providers' professional judgment that these types of projects will best meet the sustainable transport needs in Accra. Considering the individual detailed scorings, the two public transport projects were the highest with respect to job access, market access, personal security and the ability to provide stress free travel. The public transport projects received environmental impact-related scores similar to the NMT project.

The LSS framework was able to capture the local advantage of BRT over the other project types as evidenced by higher LSS. It also reflected the understanding on the part of local system providers of how each individual BRT project might serve different sustainability sub-criteria. In other words, the professional knowledge of the individual BRT corridor and its relationship to local land uses and accessibility was reflected in the scoring. For instance the Winneba Road BRT is considered to be better for personal security and stress free travel while the Tema Beach Road BRT is also considered better for education access and job access.

Table 5. Summary of LSS Scorings for Some Demographic Groups

	High Income				
Sub-criteria	**P1**	**P2**	**P3**	**P4**	**P5**
Job access	0.006	0.003	0.006	0.003	0.007
Market Access	0.003	0.001	0.003	0.001	0.003
Education access	0.003	0.002	0.003	0.001	0.003
Reliability	0.010	0.006	0.011	0.005	0.009
Affordability	0.007	0.006	0.020	0.018	0.009
Roadside commerce	0.003	0.003	0.004	0.004	0.005
Safety	0.025	0.022	0.031	0.039	0.031
NMT	0.004	0.005	0.006	0.012	0.006
Transit	0.011	0.009	0.018	0.004	0.015
Healthcare access	0.019	0.010	0.018	0.008	0.021
Activity access	0.014	0.007	0.014	0.006	0.016
Neighborhood preservation	0.008	0.008	0.010	0.009	0.012
Personal security	0.021	0.013	0.024	0.011	0.022
Stress free travel	0.011	0.007	0.013	0.006	0.012
Air pollution	0.027	0.018	0.038	0.055	0.035
Noise pollution	0.015	0.010	0.022	0.031	0.019
LSS	**0.189**	**0.131**	**0.243**	**0.211**	**0.225**
Ranking	**4**	**5**	**1**	**3**	**2**
	Low Income				
Sub-criteria	**P1**	**P2**	**P3**	**P4**	**P5**
Job access	0.007	0.004	0.007	0.003	0.008
Market Access	0.005	0.003	0.005	0.002	0.005
Education access	0.009	0.005	0.009	0.004	0.010
Reliability	0.009	0.006	0.010	0.005	0.008
Affordability	0.006	0.005	0.016	0.015	0.008
Roadside commerce	0.005	0.005	0.006	0.005	0.007
Safety	0.007	0.006	0.009	0.011	0.009
NMT	0.007	0.009	0.011	0.020	0.010
Transit	0.012	0.009	0.018	0.004	0.016
Healthcare access	0.014	0.007	0.013	0.006	0.015
Activity access	0.011	0.006	0.011	0.005	0.012
Neighborhood preservation	0.004	0.004	0.005	0.004	0.005
Personal security	0.010	0.006	0.012	0.005	0.011
Stress free travel	0.013	0.008	0.015	0.006	0.014
Air pollution	0.034	0.023	0.049	0.069	0.044
Noise pollution	0.031	0.021	0.045	0.064	0.040
LSS	**0.184**	**0.126**	**0.241**	**0.228**	**0.221**
Ranking	**4**	**5**	**1**	**2**	**3**

Table 5 presents the results after using Level II inputs from low and high income respondents only to compute the LSS. A filter was used in this case to isolate responses for these groups, and those results alone were used to compute each table. It is interesting to note that there were significant differences in the scores from the two groups, to the extent of changing the ranking of the NMT and one of the public transport projects. The high income respondents scored the NMT with lower LSS than public transport projects. However, the low income group scored the NMT project higher than the Tema Beach Road BRT, which is one of the public transport projects. This means the NMT was considered more sustainable by this group, than the Accra-Tema Beach Road BRT. This reflects the impact of including different system user groups in the participatory process.

More interestingly, there are sharp differences in the details of the results from the two groups. The high income scores for safety for all the projects range from 0.22 to 0.39, while the low income group scored 0.6 to 0.9, an indication that the high income group seemed more concerned about safety than the other group. The same trend was repeated for personal security. On the other hand the low income seemed to have more concern for environmental pollution than the high income. Similarly, the poor show more concern for NMT across all the projects, scoring 0.007 - 0.020 as opposed to 0.004 - 0.012 from the higher income respondents. In addition the low income considered the Winneba Road BRT to contribute more to affordability, healthcare access, activity access, neighborhood preservation and stress free travel than the Accra Tema Beach Road BRT. This shows how the LSS can be used to bring out the needs and concerns of different groups and communities for informed decision making.

The LSS framework rankings of the five case study projects were compared to the relative rankings assigned to them in the original studies. Table 6 indicates that the LSS framework preserved the original relative rankings of the projects. More importantly, however, the LSS framework allowed for a comparison of the merits of the public transport projects relative to projects catering for other transport modes.

Table 6. LSS Calculated for Case Study Projects.

Project Name	Category	Relative Ranking by LSS	Original Relative Ranking
Winneba Road BRT (P3)	BRT Projects	1	Highest
Accra-Tema Beach Road BRT (P5)		2	Lowest
Nima - CBD NMT(P4)	N/A	3	N/A
Motorway Extension Project (P1)	Roadway Projects	4	Highest
Lashibi Road Project (P2)		5	Lowest

CONCLUSIONS AND RECOMMENDATIONS

This paper documents an assessment of public transport projects in Accra, Ghana based on a set of criteria developed to reflect local concerns for sustainability. Levels of car ownership in Accra are still low enough that public transport is the primary alternative by which majority of residents could meet their mobility needs. Public transport is thus considered a very important mode irrespective of income, age, car ownership or employment status. This means an unsustainable public transport could have a negative impact on the economic and social life of numerous residents,

particularly on young work/study adults who make more work and school related trips. The study has also shown that men have more strict mobility needs than women and the elderly place more value on an efficient public transport system.
The LSS approach produced a result that is representative of the needs and expectations of the public and the professional judgment of local transportation professionals and the following conclusions can be drawn from the study. The LSS framework showed that BRT was deemed more sustainable than the other projects in the context of the Accra case study. The LSS framework is capable of analyzing different project types of varying scopes, which otherwise may not be comparable using conventional evaluation methods.

The limited demographic analyses presented herein, showed different responses among different types/groups of systems users. Additional analyses can be conducted to examine which of the case study projects would be the most sustainable option for each of these additional groups. Furthermore, a wider application of the framework with more projects could be used to understand and document how transport projects serve various stakeholder groups and communities. It is recommended that the study be carried out in more cities of developing countries and across a larger number of different project types to document the applicability of the LSS approach under different circumstances.

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