Chapter 2

Productivity of Construction Equipments: Earthwork Equipments

Definition: - Productivity in construction is defined as a unit output per hour. An accurate prediction of the productivity of construction equipment is critical for construction management.

1. Construction Equipment Productivity Determination

Estimating actual productivity is an essential element in estimating the time and cost required to complete construction operations.

Terminologies

Peak Productivity (Qp): is the ideal or theoretical productivity governed by design limitations only.

$$\boxed{Q_p = V \times f_s \times f_f}$$

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Where: Qp = Peak Productivity

V = Volume carried/ bucket capacity

fs = Bank Volume/loose volume

ff = Bucket fill factor

Actual Productivity: Productivity of equipment after taking care of effective working hours and job management factor on the peak productivity.

$$\boxed{Q_a = Q_p \times f_w \times f_j}$$

Where: Qa = Actual Productivity

Qp = Peak Productivity

fw = Factor to take care of effective working hours

fj= Factors to take care of the management conditions

The computation of the actual production of construction equipment is complex. But through idealization, approximation and in general simplification, one can arrive at an optimum result.

1.1Classification of construction equipment

Equipment can be broadly classified into two based on their productivity concepts: these are: - cyclic operating and continuously operating equipments.

Cyclic operating equipment: These are machines which are intentionally or unintentionally influenced by their operators. The actual productivity can be computed from:

$$\boxed{Q_a = V_n x n_o x \eta}$$

Where: Qa = Actual Productivity (Bm3/hr)

Vn = Volume per cycle (Bm3)

η= Efficiency of the equipment

no = number of cycle /Unit Time (usually Time in hours), if To is theoretical cycle time

$$n_o = \frac{60}{T_o}$$

Continuously operating equipment: These are machines that continuously operate, like pumps, conveyor belts, etc. For these kinds of machines the actual productivity can be estimated from the following formula.

$$\boxed{Q_a = V_n x a x n_o x 60 x \eta}$$

Where: Qa = Actual Productivity (Bm3/hr)

Vn = Volume per bucket

a = Number of buckets

η= Efficiency of the equipment

no = number of cycle /Unit Time (usually Time in hours)

In this course only cyclic construction equipment productivity estimation is considered.

2. **Productivity Of Shovel Family And Excavators**

Qa- Shovel family is dependent on the actual volume per cycle and the cycle time.

Vn – Volume per bucket.

- *Plate line capacity*is the bucket volume contained within the bucket when following the outline of the bucket sides.
- *Struck capacity*is the bucket capacity when the load is struck off flush with the bucket sides or volume actually enclosed by the bucket with no allowance for the bucket teeth.
- *Water line capacity*assumes a level of material flush with the lowest edge of the bucket (i.e., the material level corresponds to the water level that would result if the bucket were filled with water).
- *Heaped volume*is the maximum volume that can be placed in the bucket withoutspillage based on a specified angle of repose for the material in the bucket. The angle of repose depends on the type of material.

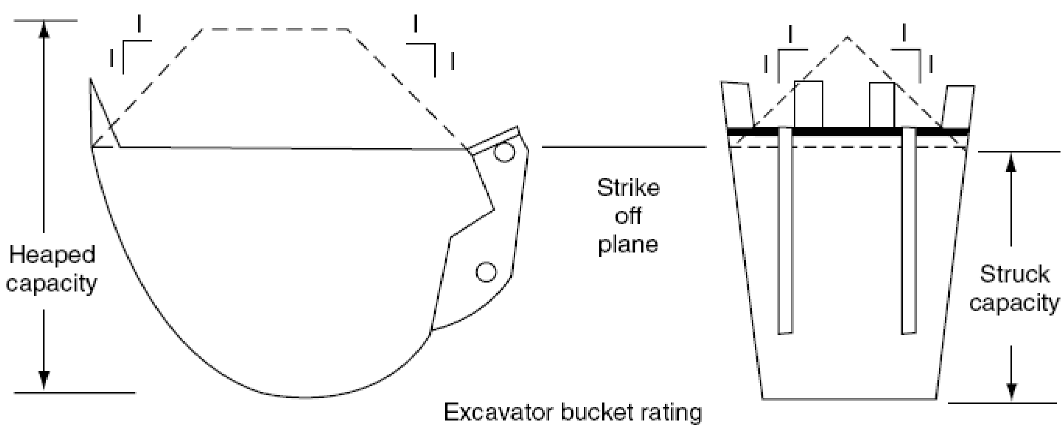


Figure 2.1 – Struck and Heaped Bucket Capacity (Caterpillar Inc.)

Commonly - Bucket ratings for the cable shovel, dragline, and cable backhoe are based on**struckvolume**.

- Thus it is often assumed that the heaping of the buckets will compensate for the swell of the soil. That is, a 5 m3 bucket would be assumed to actually hold 5 Bank m3 of material.

- A better estimate of the volume of material in one bucket load will be obtained if the nominal bucket volume is multiplied by a bucket fill factor(f)or bucket efficiency factor(ῂ).
- If desired, the bucket load may be converted to bank volume by multiplying its loose volume by the soil's load factor.

Material	Bucket Fill Factor
Common Earth, loam	0.80 – 1.10
Sand and Gravel	0.90 – 1.00
Hard Clay	0.65 – 0.95
Wet Clay	0.50 – 0.90
Rock well blasted	0.70 – 0.90
Rock, poorly blasted	0.40 – 0.70

Table 2 – 2- Bucket Fill Factors for Excavators

Example 2.1

A 2.5cy front shovel is excavating a common earth. Estimate the practical capacity of the bucket inbank measure if the load factor of the material is 0.85.

Solution

From table 2 the bucket fill factor = 0.8 taking the lower value.

Bucket load = Bucket Volume x B.F.F x f_L *= 2.5cy x 0.8 x 0.85 =* ***1.7 bcy***

Cycle Time (Tc)

In calculating the time required for a construction equipment to make one complete cycle, it is customary to break the cycle down into fixed and variable components.

$Tc = T_f + T_v$

Where:-

T_V=Variable Cycle Time - Variable time represents those components of cycle time related with travel time. Itis the time required to excavate and travel to load and travel to return to its original position after loading.

T_F = Fixed Cycle Time - Fixed time represents those components of cycle time other than travel time. It represents the time required to maneuver, change gears, start loading, and dump.

Number of cycle (n_o) =Unit Time/Tc = 60/Tc ,

Where Tc – cycle Time in minutes

2.1 Productivity of Face Shovel (Power Shovel)

A face shovels are used predominantly for hard digging above track level and for loading hauling units. Shovels are capable of developing high breakout force with their buckets, but the material being excavated should be such that it will stand a vertical bank. The size of a shovel is indicated by the size of its bucket expressed in cubic meter.

- ***Estimation of shovel production.***

The production capacity or output of a shovel is expressed in cubic meter per hour.

There are four elements in the production cycle of a shovel:-*Loading bucket, swing with load, dump load and return swing with empty bucket.*

The output varies for various type of materials to be digged. The following are the main factors which affect the output of face shovel:-

- Site Condition
- Height or Depth of cut
- Type of material
- Angle of swing
- Capacity of hauling unit and continuity of work
- Mechanical condition of shovel
- Efficiency of the operator
- Relative positions of the shovel and hauling unit
- Type of machine such as crawler or wheeled

A. Face shovel productivity factors

I. Optimum Height of Cut:-is the height that will result in a full dipper (bucket) in one pass. If the height of cut is shallow, the bucket does not fill up in one pass. The operator has a choice of making more than one passes or apply more pressure and this process increases the cycle time and eventually reduce its production. If the height of cut is higher than the optimum, then the bucket will be filled before pass completion. In this case the operator has a choice of applying less pressure on the bucket or digs upper part first then, clean bottom part later.

Percentage of optimum height (POH): $\frac{\text{Actual height}}{\text{optimum height of cut}}\ x100$

Optimum height = 30%-50%) of maximum digging height for the shovel

II. Angle of swing: The angle of swing of a shovel is the horizontal angle, expressed in degrees, between the position of the bucket when it is excavating and the position where it discharges the load. The total cycle time includes digging, swing to the dumping position, dumping and returning to the digging position. Increasing the swing angle will increase the cycle time and vise versa.

Table 2.2 Factors for height of cut and angle of swing effect on shovel production

Percentage of optimum depth	Angle of swing (degrees)						
	45	60	75	90	120	150	180
40	0.93	0.89	0.85	0.80	0.72	0.65	0.59
60	1.10	1.03	0.96	0.91	0.81	0.73	0.66
80	1.22	1.12	1.04	0.98	0.86	0.77	0.69
100	1.26	1.16	1.07	1.00	0.88	0.79	0.71
120	1.20	1.11	1.03	0.97	0.86	0.77	0.70
140	1.12	1.04	0.97	0.91	0.81	0.73	0.66
160	1.03	0.96	0.90	0.85	0.75	0.67	0.62

The probable hourly production of shovel family can calculated using the following formula.

Hourly output (cy/hr or m3/hr) =

$$P = (3600 * Q * f * k * f_1 * f_2 * t)/CT$$

Where; k = bucket fill factor (Table 8.1).

P = productivity in cy/hr or m³/hr.

Q = bucket capacity in <u>loose</u> cy or m³.

f = earth volume change conversion factor.

f_1 = swing-depth factor (Table 8.2).

f_2 = job and management conditions.

t = operating time factor.

CT = cycle time in seconds.

Generally the output of the face shovel can be estimated by the following formula.

Hourly production (m3/hr) = q x (3600/C) x Efficiency

Where: q = production in m^3 per cycle

= Heaped capacity x Swell factor x Bucket factor.

Manufacturer of the equipment used to provide a graph b/n bucket size Vs Production/hr.Since this gives production in ideal conditions, the figures thus obtained should be scaled down to expected production by using ***efficiency factor*** and ***bucket fill factor***.

Table 2.3 bucket fill factor

Bucket Fill Factor	
Sand, gravel, common earth	90%
Well blasted rock	70%
Poorly blasted rock	50%

The above figures are for crawler type of tractor shovel, however for wheel shovels, bucket factor is about 10% lesser than those mentioned above.

Example2.2

A hydraulic front shovel excavating common earth has a heaped capacity of 1.5 cyd. Its maximum digging height is given by the manufacturer as 7m. the average angle of swing 120^o. the average height of cut is 2.94m. What is the hourly rate of production in m^3bm/hr, if the shovels cycle time is 19 sec? Take the shovel's optimum height of cut as equal to 30% of its maximum digging height. Assume the job efficiency and bucket load factor to be 50min/hr and 0.8 respectively.

Solution

Bucket capacity in m3 = 1.5 *0.76 = 1.14m^3 loose measure

Earth volume conversion factor from loose to bank = 0.8

Cycle time Tc= 19sec

Optimum height of cut = 7*0.30 = 2.10m

%age of optimum height = $\frac{2.94}{2.10}\ x100$ =140%

Depth- swing factor (from table 2.2) f1 = 0.81, bucket fill factor = 0.9 from table 2.3.

Job efficiency = 50min/60min = 0.83

Rate of hourly production

P = (3600* Q *f * k * f1 *η)/Tc = (3600 * 1.14 * 0.8 * 0.9 * 0.81 * 0.83) / 19sec

= 104.56 m^3bm/hr.

2.2 Productivity of Dragline

A dragline excavator is especially useful when there is need for extended reach in excavating or when material must be excavated from under water. Drag bucket and clamshells are both attachments hung from a lattice boom crane. The output of a dragline is best obtained from field measurement. But it can also be estimated by productivity determination formula.

Output or performance of dragline depends on the following factors:

- Nature of the soil.
- Depth of cut.
- Angle of swing.
- Length of boom
- Method of disposal
- Capacity of hauling units, if employed.
- Mechanical condition of the dragline.
- Efficiency and skill of the operator.
- Management conditions.
- Size and type of bucket.
- Working cycle

Data are taken from “Liebher’s Technical Hand Book Earth moving Product line”.

Drag Line Production = Bucket capacity (m3) x Number of cycle (C) x f

Where, C = Theoretical Cycles/hr, estimated number of cycle for dragline = 120 Cycles/hr

f = Correcting factor

f = f1 x f2 x f3 x f4 x f5 x f6 x f7

The correction factors are all factors affecting the productivity of the dragline.

***f_1* - Fill factor**		
	Class	**Fill factor**
1	**Sand or fine gravel**	**1.1 to 1.2**
	a) **Dry**	**1.0 to 1.1**
	b) **Damp**	**0.9 to 0.8**
	c) **Wet**	
2	**Clay**	**0.95 to 1.0**
	a) **Sandy clay, dry**	**0.9 to 0.95**
	b) **Cohesive, dry**	**0.88 to 0.9**
	c) **Very cohesive, hard**	
3	**Earth with sand or gravel, dry**	**0.85 to 0.88**
4	**Top Soil**	**0.82 to 0.85**
	a) **Sandy clay**	**0.80 to 0.82**
	b) **Clay damp**	
5	**Clay with sand or gravel, damp**	**0.75 to 0.80**
6	**Slatelike rock, gravel**	**0.72 to 0.75**
7	**Gravel with clay, hard**	**0.70 to 0.72**
8	**Clay with large size gravel, damp**	**0.68 to 0.70**

f_2 – Digging factor				
Boom Length (m)	12	18	24	30
Digging factor, f_2	0.86	0.79	0.72	0.65

f_3 – Hoist factor				
Boom Length (m)	12	18	24	30
Hoist factor,f_3	0.95	0.92	0.9	0.87

f_4 – Swing factor (Simultaneous swing and hoist)			
Angle of Swing (deg)	90°	120°	180°
Swing factor, f_4	0.98	0.95	0.91

f_5 – Loading factor			
Method of dumping	Truck	Hopper	Stock pile
Loading factor, f_5	0.96	0.95	1

f_6 – Job efficiency factor			
Actual working time	60 min/hr	50 min/hr	40 min/hr
Job efficiency factor, f_6	1	0.83	0.67

f_7 – Operator factor			
Operator	Experienced	Average	Beginner
Operator factor, f_7	1	0.95	0.85

Example 2.3

An experienced operator has to excavate ‘wet gravel’ with a dragline capacity of 2.3 m^3. The boom length is 18m and the swing angle will be 120 degrees. The material is dumped onto stockpile. Actual working time is 50 min per hour.

Solution

Drag line production = Bucket capacity x C x f.

Where C = theoretical cycles/hr = 120 cycles/hr

= 2.3 x 120 x f

Where f = f1 x f2 x f3 x f4 x f5 x f6 x f7 = 0.8x0.79x0.92x0.95x1.0x0.83x1.0

= 0.4588

Therefore, Drag line production = 2.3x120x0.4588

= **126.4 m3/hr**

2.3 Productivity of clamshell

Clamshell excavators provide the means to excavate vertically to considerable depth and it is capable of working at, above and below ground level.

The method of estimating the productivity of clamshell is similar with thedragline.

Clamshell Production (m3/hr)= Clamshell Capacity (m3) x C x f

Where, C = Theoretical Cycles/hr = 120 Cycles/hr

f = Correcting factor

= f1 x f2 x f3 x f4 x f5 x f6 x f7

f_1 – Fill factor, Same as those for dragline.

f_2 – Digging factor					
Clamshell capacity (m^3)	1	2	3	4	5
Digging factor, f_2 =	0.98	0.97	0.96	0.96	0.95

f_3 – Hoist factor (considering average rope speed of 50m/min)				
Digging depth (m)	5	10	15	20
Hoist factor, f_3 =	0.88	0.76	0.64	0.52

f_4 – Swing factor				
Swing Angle (deg)	60	90	120	180
Swing factor, f_4=	1.2	1	0.98	0.9

f_5 – Dump factor			
Method of dumping	Truck	Hopper	Stock pile
Dump factor, f_5 =	0.9	0.95	1

f_6 – Job efficiency factor			
Actual working time	60 min/hr	50 min/hr	40 min/hr
Job efficiency factor, f_6 =	1	0.83	0.67

f_7 – Operator factor			
Operator	Experienced	Average	Beginner
Operator factor, f_7 =	1	0.95	0.85

Example 2.4

An average operator has to excavate 'damp sand' with a clamshell of 2.0 m^3. The digging depth is 10m and the swing angle will be 120 degrees. The sand is added into trucks and actual working time is 50 min/hr.

Clamshell production = Clamshell capacity x C x f.

Where C = theoretical cycles/hr

= 2.0 x 120 x f

Where, f = f1 x f2 x f3 x f4 x f5 x f6 x f7

= 1.0 x 0.97 x 0.76 x 0.98 x 0.9 x 0.83 x 0.95

= 0.5127

Therefore, Clamshell Production = 2.0x120x0.5127

= 123.0 m3/hr

2.4 Productivity of excavator/ Hoe

Hoes are used primarily to excavate below the natural surface of ground on which the machine rests. In the selection of a hoe for use on a project the following factors must be considered.

- Maximum excavation depth
- Maximum working radius required for digging and dumping
- Maximum dumping height required
- Hoisting capability required

The same elements that affect shovel production are applicable to hoe excavation operations. Hoes cycle times are approximately 20% longer in duration than those of a similar size shovel because the hoisting distance is greater as the boom and stick must be fully extended to dump the bucket. Optimum depth of cut for a hoe will depend on the type of material being excavated and bucket size and type.

The basic production formula a hoe used as an excavator is:-

$$\text{Hoe (excavation) production} = \frac{3{,}600 \text{ sec} \times Q \times F}{t} \times \frac{E}{60\text{-min hour}} \times \frac{1}{\text{volume correction}}$$

where

Q = heaped bucket capacity in lcy

F = bucket fill factor for hoe buckets

t = cycle time in seconds

E = efficiency in minutes per hour

volume correction = for loose volume to bank volume, $\frac{1}{1 + \text{swell factor}}$;

for loose volume to tons, $\frac{\text{loose unit weight, lb}}{2{,}000 \text{ lb/ton}}$

Steps for estimating production of Excavator/hoe:

Step-1: Obtain the heaped bucket load volume (in Lm3) from the manufacturers' data sheet.Heaped bucket capacity ratings for Excavator buckets assume a 1:1 material angle of repose.

Step-2: Material Type

Step-3: Apply a bucket fill factor based on the type of machine and the class of material being excavated. Refer Table D-1.

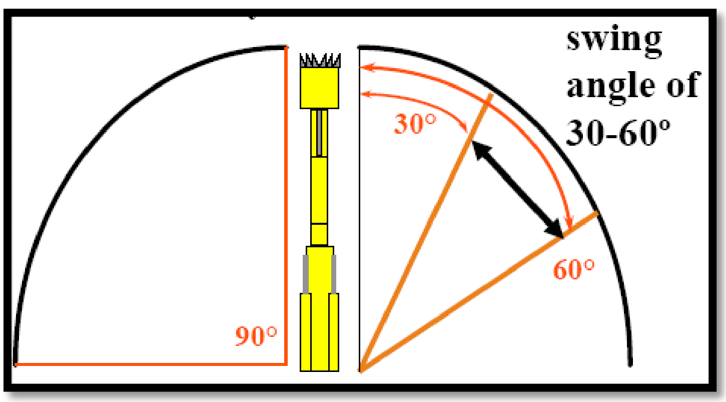
Table D-1 Fill factor for hydraulic Hoe (Caterpillar Inc.)	
Moist loam/ sandy clay	100-110%
Sand and gravel	95-100%
Rock-poorly blasted	40-50%
Rock-well blasted	60-75%
Hard, tough clay	80-90%

Step-4: Estimate cycle time (load, swing, dump and swing empty). Refer Table D-2.Swing is influenced by job conditions such as obstructions and clearances.

Table D-2 Excavation Cycle times for hydraulic crawler hoes under average condition					
Bucket Size (cy)	Load Bucket (sec)	Swing Loaded (Sec)	Dump Bucket (Sec)	Swing empty (sec)	Total cycle (sec)
<1	5	4	2	3	14
1-1 ½	6	4	2	3	15

2-2 ½	6	4	3	4	17
3	7	5	4	4	20
3 ½	7	6	4	5	22
4	7	6	4	5	22
5	7	7	4	6	24

Small machines swing faster than large ones.Cycle times given in the above table are based on swing angle of ***30-60°***.



Step-5: Check depth of cut. Refer Table D-3.Typical cycle times are for depth of cut between 40-60% of maximum digging depth.

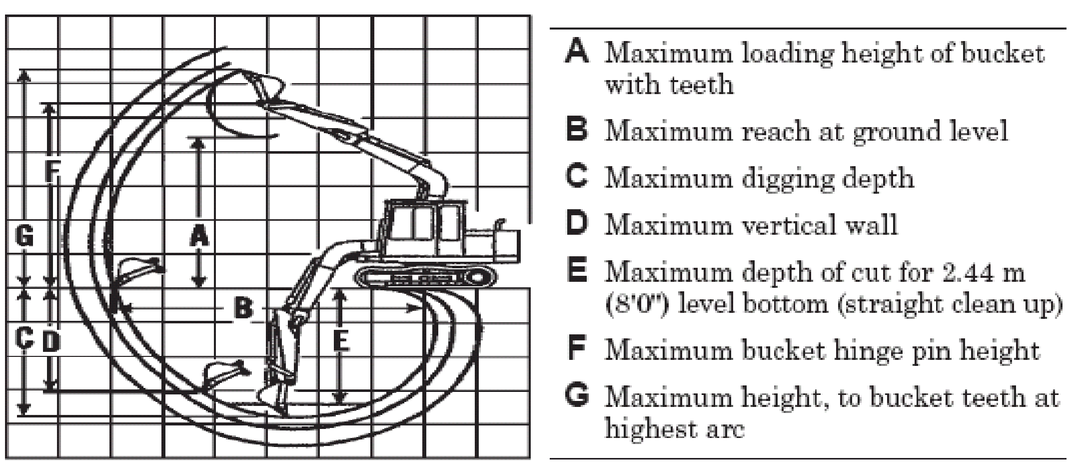


Table D-3: Representative dimensions, loading clearance, and filling capacity, hydraulic crawler Hoe

Size bucket (cy)	Stick length (ft)	Maximum reach @ ground level (ft)	Maximum digging depth (ft)	Maximum loading height (ft)	Lifting capacity at 15 ft			
					Short stick		Long stick	
					Front (lb)	Side (lb)	Front (lb)	Side (lb)
3/8	5–7	19–22	12–15	14–16	2,900	2,600	2,900	2,600
3/4	6–9	24–27	16–18	17–19	7,100	5,300	7,200	5,300
1	5–13	26–33	16–23	17–25	12,800	9,000	9,300	9,200
$1\frac{1}{2}$	6–13	27–35	17–21	18–23	17,100	10,100	17,700	11,100
2	7–14	29–38	18–27	19–24	21,400	14,500	21,600	14,200
$2\frac{1}{2}$	7–16	32–40	20–29	20–26	32,600	21,400	31,500	24,400
3	10–11	38–42	25–30	24–26	32,900*	24,600*	30,700*	26,200*
$3\frac{1}{2}$	8–12	36–39	23–27	21–22	33,200*	21,900*	32,400*	22,000*
4	11	44	29	27	47,900*	33,500*		
5	8–15	40–46	26–32	25–26	34,100†	27,500†	31,600†	27,600†

Step-6: Check loading height:-Does the selected Excavator/hoe have the reach capability to load the haul unit. Refer table D-3.

Step-7: Efficiency factor:-The three primary conditions that control the efficiency of excavator loading operations are.

Bunching: In actual operation cycle times are never constant. When loading haul units they will sometimes bunch. The impact of bunching is a function of the number of haul units.

Operator efficiency: How good is the operator?

Equipment availability: Are the haul units in good condition and repair? They will be available x% of the time.

Step-8: ***productivity calculation.***

$$\boxed{\text{Step 1} \times \text{Step 3} \times \frac{\text{Step 7}}{\text{Step 4}} = \text{LCY / hr}}$$

Step-9: Convert production to Bank Volume (BCY)

Table D-4 Swell factor

Material	Bank weight lb/cu yd	Bank weight kg/m^3	Loose weight lb/cu yd	Loose weight kg/m^3	Percent swell	Swell factor
Clay,dry	2,700	1,600	2,000	1,185	35	0.74
Clay, wet	3,000	1,780	2,200	1,305	35	0.74
Earth, dry	2,800	1,660	2,240	1,325	25	0.80
Earth, wet	3,200	1,895	2,580	1,528	25	0.80
Earth and gravel	3,200	1,895	2,600	1,575	20	0.83
Gravel, dry	2,800	1,660	2,490	1,475	12	0.89
Gravel, wet	3,400	2,020	2,980	1,765	14	0.88
Limestone	4,400	2,610	2,750	1,630	60	0.63
Rock, well blasted	4,200	2,490	2,640	1,565	60	0.63
Sand, dry	2,600	1,542	2,260	1,340	15	0.87
Sand, wet	2,700	1,600	2,360	1,400	15	0.87
Shale	3,500	2,075	2,480	1,470	40	0.71

Production formula

$$\text{Production} = \frac{3{,}600\ \text{sec} \times Q \times F \times (\text{AS}:\text{D})}{t}\left(\frac{E}{60-\text{min hr}}\right)\left(\frac{1}{\text{Vol. Correction}}\right)$$

Where, Q = Heaped Capacity

F = Bucket Fill Factor

AS:D = Angle of swing and depth (height) of cut correction

t = Cycle time in seconds E = Efficiency min/hr

Volume correction for loose volume to bank volume.

$$\frac{1}{1+\text{swell factor}}$$

Example2.5A crawler hoe having a 3½-cy bucket is being considered for use on a project to excavate very hard clay from a borrow pit. The clay will be loaded into trucks having a loading height of 9 ft 9 in. Soil- boring information indicates that below 8 ft, the material changes to an unacceptable silt material. What is the estimated production of the hoe in cubic yards bank measure, if the efficiency factor is equal to 50-min/hour?

Solution

Step-1: Size of bucket = 3½-cy

Step-2: Bucket fill factor, Table D-1 gives 80-90%, Use averageBucket fill factor = (80+90)/2 = 85%.

Step-3: Typical cycle element times

Optimum depth of cut is 30-60% of maximum digging depth. From Table D-3 for a 3½ -CY size Hoe, maximum digging depth is 23-27 ft, Depth of excavation 8 ft.

(8ft/23ft) x 100 = 34% ≥ 30% okay!

(8ft/27ft) x 100 = 30% ≥ 30% okay!

Therefore under average conditions and for 3½-Cy Size hoe, cycle times from Table D-2:

1. Load Bucket	7sec	Very hard clay
2. Swing with load	6sec	Load trucks
3. Dump load	4sec	Load trucks
4. Return swing	5sec	
Cycle time	**22sec**	

Step-4: Efficiency factor, 50 min/hour

Step-5: Class of material, hard clay Swell 35% (Table D-4)

Step-6: Probable production

$$\frac{3{,}600 \text{ sec/hr} \times 3\tfrac{1}{2} \text{ cy} \times 0.85}{22 \text{ sec/cycle}} \times \frac{50 \text{ min}}{60 \text{ min}} \times \frac{1}{(1+0.35)} = 300 \text{ bcy/hr}$$

Check maximum loading Height to ensure the hoe can service the trucks. From Table D-3, 21 to 22 *ft*.21ft > 9ft 9in. Okay.

Exercise 2.1

An excavator have a 3cy bucket is being considered for use on a project to excavate very hard clay with a swell factor of 35% from a borrow pit. The clay will be loaded into trucks having a loading height of 10 ft. The average cycle time for the excavator to load bucket, swing, dump, return is 20 second. The efficiency factor is equal to a 50-min hour? What is the estimated production of the excavator in cubic yards bank measure?

2.5 Productivity of Loader

Loaders are used extensively in construction operations to handle and transport material, to load haul units, to excavate, and to charge aggregate bins at both asphalt and concrete plants. The loader is a versatile piece of equipment designed to excavate at or above wheel or track level. Many factors affect loader production: *operator skill, extent of prior loosening of the material, slope of the operating area, height of the material, climate, and haul-unit positioning*.

The two critical factors to be considered in selecting a loader are:-

- The type of material and
- The volume of material to be handled

The production rate for wheel loader will depend on the:

1. Fixed cycle time required to load the bucket, maneuver with four reversals of direction, and dump the load.
2. Time required travelling from the loading to the dumping position.
3. Time required returning to the loading position.
4. Volume of material hauled on each cycle.

Table A-1 Bucket fill factors for wheel and truck loader

Material	Wheel loader fill factor (%)	Track loader fill factor (%)
Loose material		
Mixed moist aggregates	95–100	95–100
Uniform aggregates		
up to $\frac{1}{8}$ in.	95–100	95–110
$\frac{1}{8}-\frac{3}{8}$ in.	90–95	90–110
$\frac{1}{2}-\frac{3}{4}$ in.	85–90	90–110
1 in. and over	85–90	90–110
Blasted rock		
Well blasted	80–95	80–95
Average	75–90	75–90
Poor	60–75	60–75
Other		
Rock dirt mixtures	100–120	100–120
Moist loam	100–110	100–120
Soil	80–100	80–100
Cemented materials	85–95	85–100

Table A-2 Representative specifications for wheel loader

Size, heaped bucket capacity (cy)	Bucket dump clearance (ft)	Static tipping load, @ full turn (lb)	Maximum forward speed				Maximum reverse speed				Raise/dump/lower cycle (sec)
			First (mph)	Second (mph)	Third (mph)	Fourth (mph)	First (mph)	Second (mph)	Third (mph)	Fourth (mph)	
1.25	8.4	9,600	4.1	7.7	13.9	21	4.1	7.7	13.9	—	9.8
2.00	8.7	12,700	4.2	8.1	15.4	—	4.2	8.3	15.5	—	10.7
2.25	9.0	13,000	4.1	7.5	13.3	21	4.4	8.1	14.3	23	11.3
3.00	9.3	17,000	5.0	9.0	15.7	26	5.6	10.0	17.4	29	11.6
3.75	9.3	21,000	4.6	8.3	14.4	24	5.0	9.0	15.8	26	11.8
4.00	9.6	25,000	4.3	7.7	13.3	21	4.9	8.6	14.9	24	11.6
4.75	9.7	27,000	4.4	7.8	13.6	23	5.0	8.9	15.4	26	11.5
5.50	10.7	37,000	4.0	7.1	12.4	21	4.6	8.1	14.2	24	12.7
7.00	10.4	50,000	4.0	7.1	12.7	22	4.6	8.2	14.5	25	16.9
14.00	13.6	98,000	4.3	7.6	13.0	—	4.7	8.3	14.2	—	18.5
23.00	19.1	222,000	4.3	7.9	13.8	—	4.8	8.7	15.2	—	20.1

Table A-3 Representative specification for truck loaders.

Size, heaped bucket capacity (cy)	Bucket dump clearance (ft)	Static tipping load (lb)	Maximum forward speed (mph)	Maximum reverse speed (mph)	Raise/ dump/ lower cycle (sec)
1.00	8.5	10,500	6.5	6.9	11.8
1.30	8.5	12,700	6.5	6.9	11.8
1.50	8.6	17,000	5.9*	5.9*	11.0
2.00	9.5	19,000	6.4*	6.4*	11.9
2.60	10.2	26,000	6.0*	6.0*	9.8
3.75	10.9	36,000	6.4*	6.4*	11.4

Table A-4 Fixed cycle time for loaders

Loader size, heaped bucket capacity (cy)	Wheel loader cycle time* (sec)	Track loader cycle time* (sec)
1.00–3.75	27–30	15–21
4.00–5.50	30–33	—
6.00–7.00	33–36	—
14.00–23.00	36–42	—

Example 2.6A Cat 950G wheel loader with a 4.25 lcy heaped bucket is to be used to movefairly loose stockpiled dirt onto a conveyor running under the road. The conveyor is carryingthe dirt to another part of the site. The dirt will be used to fill that side of the project site. TheCat Performance Manual suggests a cycle time (load, dump, maneuver) of about 55 s for the
way you have the work setup. The conveyor will haul about 280 lcy/h. Will the production of the loader keep up with the conveyor?

a. How much dirt (lcy) can be moved in one production cycle?
b. What is the work hour productivity if the operator works 50 min per 60-min hour?

Solution:

a) V = 4.25 lcy/cycle. In one production cycle only the capacity of the bucket will be moved.
b) Work hour productivity = [(Bucket load volume(lcy)) *(50 min/60min)]*(60min/0.92min)

= [(4.25 lcy)(50 min)]/0.92min/cycle

= **231 lcy/work hour**

From the result the loader will not keep up with the conveyor. Because 231 lcy/hour<280 lcy/h, Therefore, either two small loaders has to be used or a larger bucket need to be attached to the loader.

Exercise 2.2

A 4-cy wheel loader will be used to load trucks from a quarry stockpile of uniform aggregates 1in and over in size. The haul distance will be negligible. The aggregate has a loose unit weight of 2750Ib/cy. Estimate the loader production in tons based on a 50min/hr efficiency factors. Use conservative cycle time and fill factor.

2.6 Productivity of a Dozer

A dozer has no set volumetric capacity. There is no hopper or bowl to load; instead, the amount of material the dozer moves is dependent on the quantity that will remain in front of the blade during the push.

The production of dozer mainly depends upon the following factors:

- Size and condition of the dozer
- Distance traveled by the dozer
- Speed of operation
- Characteristic of soil being handled
- Surface on which dozer is operating
- Efficiency

The major factors that control dozer production rate are:

- Condition of the material
- Blade type
- Cycle time

Condition of the material

The type and condition of the material being handled affects the shape of the pushed mass in front of the blade.

- Cohesive materials (clays) will ‘boil’ and heap.
- Materials that exhibit a slippery quality or those with high mica content will ride over the ground and swell out.
- Cohesion less materials (sands) are known as “dead” materials because they do not exhibit heap or swell properties.

Figure 2.1 clay material boiling in front of the blade and cohesion less and loam in front of the blade

Blade type

By design, straight blades roll material in front of the blade, and universal and semi universal blades control side spillage by holding the material with in blade.

Blade capacity is a function of a ***blade type*** and ***physical size***.

Blade volumetric load

The load that a blade will carry can be estimated by several methods:

i. Manufacturer's blade rating

ii. Previous experience (similar material, equipment, and work conditions)

iii. Field measurements

Manufacturers Blade rating

Manufacturers may provide a blade rating based on available standards and the purpose the standard is to provide uniform method for calculating blade capacity. The manufacturer may use the following formula to estimate the productivity of a dozer.

$$V_s = 0.8\, W H^2$$
$$V_u = V_s + ZH(W - Z) \tan x^o$$

Where

V_s	=	capacity of straight or angle blade, in lcy
V_u	=	capacity of universal blade, in lcy
W	=	blade width, in yd, exclusive of end bits
H	=	effective blade height, in yd
Z	=	wing length measured parallel to the blade width, in yd
x	=	wing angle

Previous experience

Properly documented past experience is an excellent blade load estimating method. Documentation requires that the excavated area be cross sectioned to determine the total volume of material moved and that the number of dozer cycle recorded.

The following procedure can followed for measuring the blade load.

1. Obtain a normal blade load.
   - The dozer pushes a normal blade load on to a level area.
   - Stop the dozer's forward motion. While raising the blade move forward slightly to create asymmetrical pile.
   - Reverse and move away from the pile.
2. Measurement
   - Measure the height (H) of the pile at the inside edge of each rack.
   - Measure the width (W) of the pile at the inside edge of each rack.
   - Measure the greatest length (L) of the pile. This will not necessarily be at the middle.

Computation

Average both the two-height and the two-width measurements. If the measurements are in feet, the blade load in loose cubic yards (lcy) is calculated by the formula.

Blade load (lcy) = 0.0139HWL

Example 2.7

The measurement from a blade-load test were H_1 = 4.9 ft, H_2 = 5.2 ft, W_1 = 6.9 ft, W_2 = 7.0 ft,and L = 12.6 ft. What is the blade capacity in loose cubic yards for the tested material?

$$H = \frac{4.9 + 5.2}{2} = 5.05 \text{ ft}, \qquad W = \frac{6.9 + 7.0}{2} = 6.95$$

$$\text{Blade Load (lcy)} = 0.0139HWL = 0.0139(5.05)(6.95)(12.6) = 6.15 \text{ lcy}$$

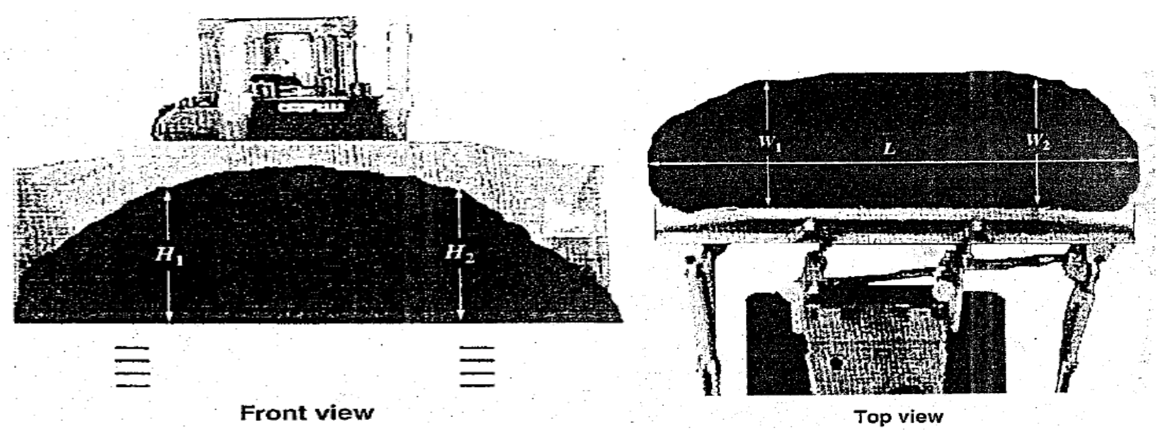


Figure 2.3 measurements for calculating blade load.

Cycle time

The sum of the time required for pushing, backtracking, and maneuver into position to push represents the complete dozer cycle. The time required to push and back track can be calculated for each dozing situation considering the travel distance and obtaining a speed from the machine's performance chart.

Dozing is generally performed at slow speed, 1.5 to 2 mph.

Return Speed is usually the maximum that can be attained in the distance available. When using performance charts to determine possible speeds, remember the chart identifies instantaneous speed.in calculating cycle duration, the estimator must use an average speed that accounts for the time required to accelerate to the attainable speed as indicated by the chart.

For distances less than 100 ft, the operator cannot get the machine past the second gear.

The following example demonstrates the process for estimating dozer production.

Table B-1 Typical dozer fixed cycle times	
Operating condition	**Time (min)**
Power-shift transmission	0.05
Direct-drive transmission	0.1
Hard digging	0.15

Table B-2 Typical dozer operating speeds	
Operating conditions	**Speeds**
Dozing	
Hard materials, haul 30m or less	2.4 Km/hr
Hard materials, haul over 30m	3.2 Km/hr
Loose materials, haul 30m or less	3.2 km/hr
Loose material haul over 30m	4.0 km/hr
Return	
30m or less	Max reverse speed in second range (power shift) or reverse speed in gear used for dozing (direct drive)
Over 30m	Max reverse speed in third range (power shift) or highest reverse speed

Example 2.8

A power-shift crawler tractor has a rated blade capacity of 7.65Lm3. The dozer is excavating loose common earth and pushing a distance of 200ft (61m) with speed of 4km/hr. Maximum reverse speed in third range is 8 km/hr. Estimate the production of the dozer, if job efficiency is 50 min/hr.

Solution

Fixed time = 0.05 min (From Table B-1) and Dozing speed = 4.0 km/hr given but can be obtained from Table B-2.

- Dozing time = 61m /(4 km/hr x 16.7 m/min) = 0.91 minute: 1km/hr = 16.7 m/min
- Return time = 61m /(8 km/hr x 16.7 m/min) = 0.45 min
- Cycle time = (0.05+0.91+0.45)min = 1.41min
- Production = 7.65 Lm3 x [(50min/hr)/(1.41min)] = 271 Lm3/hr

Use of graphs, charts and curves for estimating production

Production curves for estimating the amount of material that Caterpillar bulldozers can push are usually available by the manufacturers.These curves are published in the Caterpillar Performance Handbook.The bulldozer production curves give maximum uncorrected production for universal, semi-universal, and straight blades and are based on the following conditions.

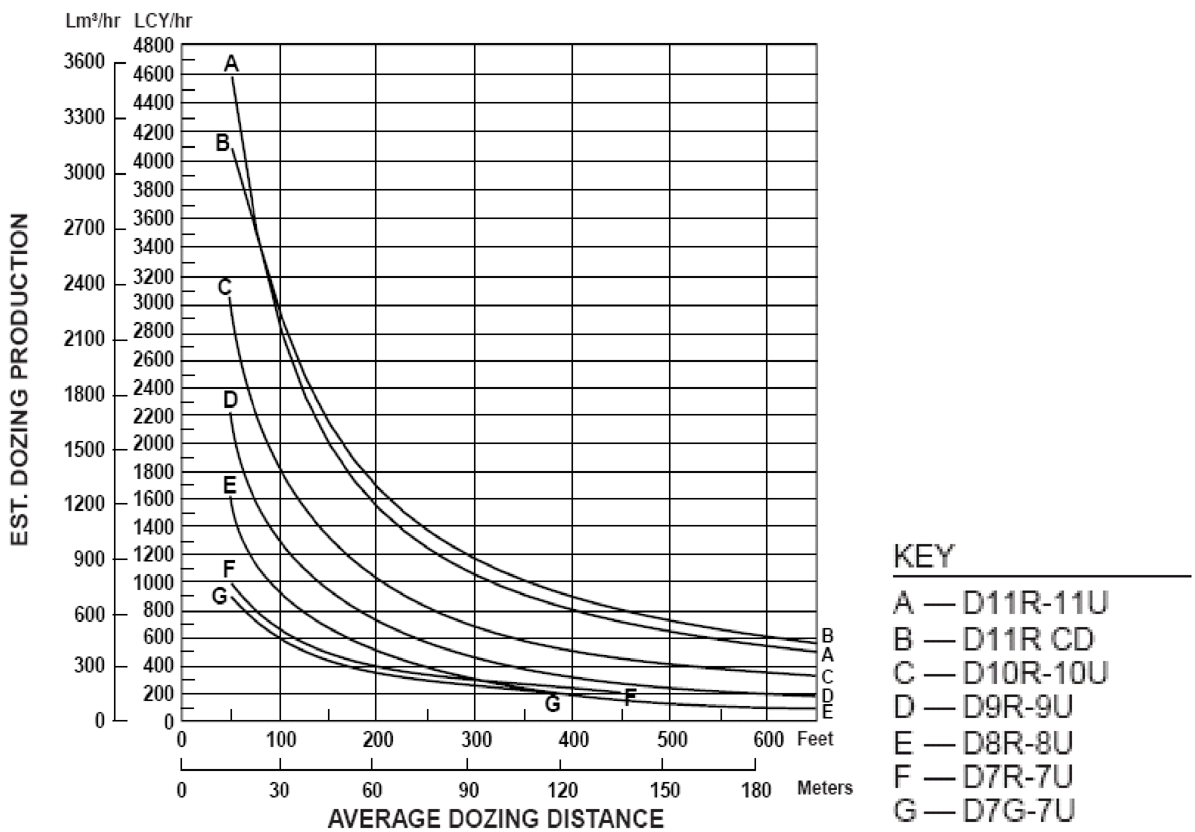
- 100% efficiency (60 minute hour-level cycle).
- Power shift machines with 0.05 min. fixed times.
- Machine cuts for 15 m (50 feet), then drifts blade load to dump over a high wall. (Dump time — 0 sec.)
- Soil density of 1370 kg/Lm^3 (2300 lb/LCY).

$$\boxed{\begin{array}{r}\text{Production } (\text{Lm}^3/\text{hr}) \\ (\text{LCY/hr})\end{array} = \begin{array}{c}\text{Maximum} \\ \text{production}\end{array} \times \begin{array}{c}\text{Correction} \\ \text{factors}\end{array}}$$

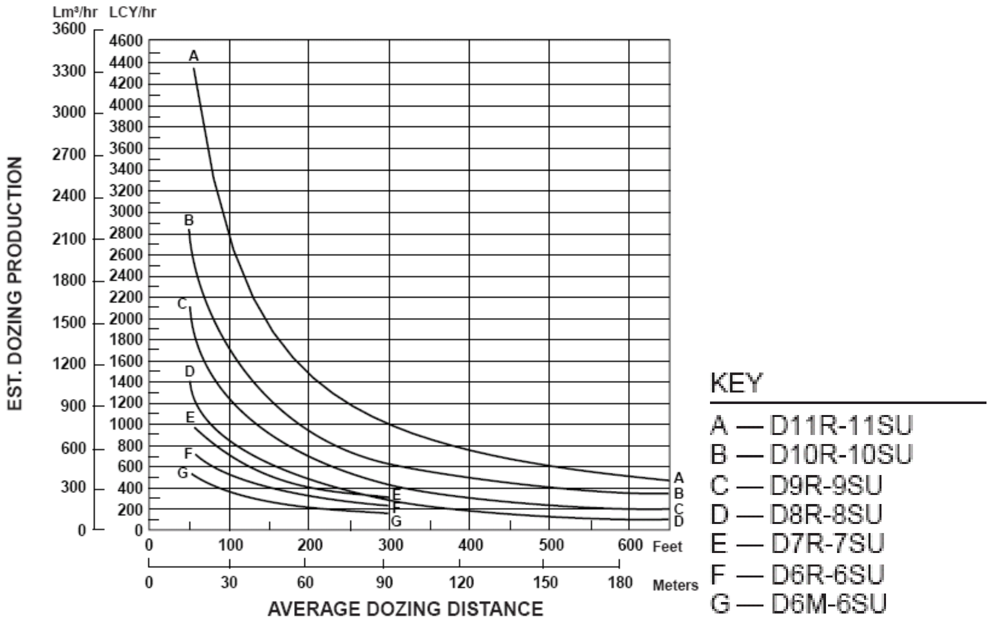
To obtain estimated production in bank cubic meters or bank cubic yards, appropriate load factor from the Tables section should be applied to the corrected production as calculated above.

$$\text{Production } Bm^3/hr\ (BCY/h) = Lm^3/hr\ (LCY/h) \times LF$$

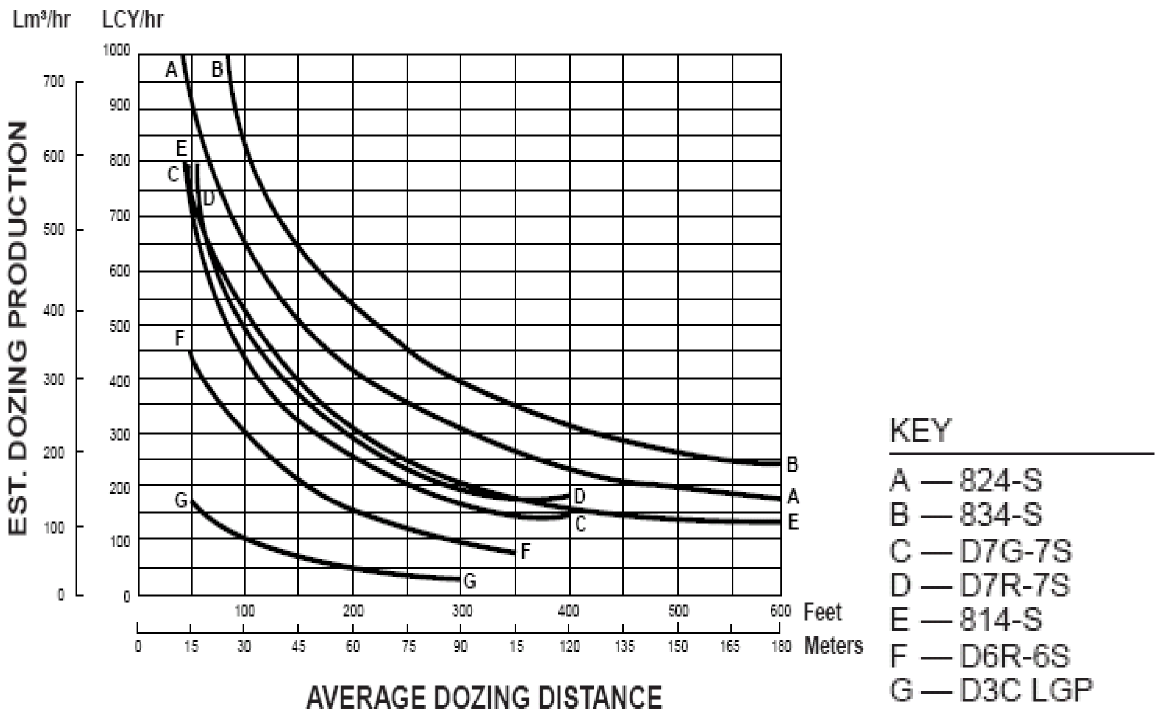
ESTIMATED DOZING PRODUCTION • Universal Blades • D7G through D11R

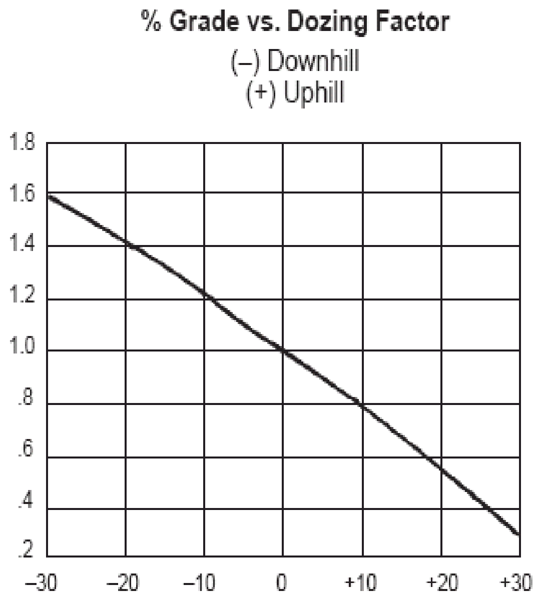


ESTIMATED DOZING PRODUCTION • Semi-Universal Blades • D6M through D11R



ESTIMATED DOZING PRODUCTION
Straight Blades • D3, D6, D7, 814, 824, 834





JOB CONDITION CORRECTION FACTORS

	TRACK-TYPE TRACTOR	WHEEL-TYPE TRACTOR
OPERATOR —		
Excellent	1.00	1.00
Average	0.75	0.60
Poor	0.60	0.50
MATERIAL —		
Loose stockpile	1.20	1.20
Hard to cut; frozen —		
with tilt cylinder	0.80	0.75
without tilt cylinder	0.70	—
cable controlled blade	0.60	—
Hard to drift; "dead" (dry, non-cohesive material) or very sticky material	0.80	0.80
Rock, ripped or blasted	0.60-0.80	—
SLOT DOZING	1.20	1.20
SIDE BY SIDE DOZING	1.15-1.25	1.15-1.25
VISIBILITY —		
Dust, rain, snow, fog or darkness	0.80	0.70
JOB EFFICIENCY —		
50 min/hr	0.83	0.83
40 min/hr	0.67	0.67
BULLDOZER*		
Adjust based on SAE capacity relative to the base blade used in the Estimated Dozing Production graphs.		
GRADES — See following graph.		

Example 2.9

Determine average hourly production of a D8R/8SU (with tilt cylinder) moving hard-packed clay an average distance of 45 m (150 feet) down a 15% grade, using a slot dozing technique. Estimated material weight is 1600 kg/Lm3 (2650 lb/LCY). Operator is average. Job efficiency is estimated at 50 min/hr.

Solution

Uncorrected Maximum Production = 458 Lm3/hr (600 LCY/hr) from Estimated dozer production graph for Semi universal blade.

Applicable Correction Factors:

Hard-packed clay is “hard to cut” material –0.80
Grade correction (from graph) . . . .–1.30
Slot dozing . . . .–1.20
Average operator . . . .–0.75
Job efficiency (50 min/hr) . . . .–0.83
Weight correction . . . .(2300/2650)–0.87

$$
\begin{aligned}
\text{Production} &= \text{Maximum Production} \times \text{Correction Factors} \\
&= (600\ \text{LCY/hr})\,(0.80)\,(1.30)\,(1.20)\,(0.75)\,(0.83)\,(0.87) \\
&= 405.5\ \text{LCY/hr}
\end{aligned}
$$

To obtain production in metric units, the same procedure is used substituting maximum uncorrected production in Lm^3.

$$
\begin{aligned}
&= 458\ \text{Lm}^3/\text{h} \times \text{Factors} \\
&= 309.6\ \text{Lm}^3/\text{h}
\end{aligned}
$$

Productivity of Rippers

Output of rippers depend upon characteristic of soil, size of the dozer, speed of the machine, shape and size of the ripper tooth, number of shanks used, and depth and width of ripping pass.However, the following are the formulae used in general for calculating the output of ripper.

Production per hour = (Bank volume ripped per pass) x (No. of passes per hour

Where,

Bank volume ripped per pass = (Length of pass)x(Width of ripping pass)x(Depth of penetration)x(Efficiency)

No. of passes per hour = 60/(Time for making one pass in min.)

Time taken in one pass = (Length of pass/Traveling speed) + Turn round

2.7 Productivity of Scraper

Scrapers are designed to load, haul, and dump loose material. The greatest advantage is theirversatility. They can be used for a wide variety of material types and are economical for a range of haul distances and conditions. They are a compromise between a bulldozer, anexcavator, and a dump truck. Scrapers are articulated, tractor powered, and pull a bowl thatholds the soil.

The capacity of the scraper bowl can be measured by volume or weight. When the capacity or the weight is exceeded, operating efficiency decreases. Scraper volume is measured in two ways in loose cubic yards. That is in Struck volume and Heaped volume. The scrapers can be assisted by dozer or pusher during its operation

Dozer-assisted means that the dozer makes contact with the back bale of the scraper as itstarts into the hole. The dozer is actually providing most of the pushing power to not only make the cut, but also to transport the full bowl through and out (boost) of the cut. This greatly optimizes what a bulldozer is designed to do and greatly reduces the power needed by the scraper to excavate and start hauling when fully loaded. It is an ideal pairing of equipment to optimize the capabilities of both.

To determine the number of scrapers that can be matched to one pusher or dozer, the pusher cycle time must be determined. This cycle time includes match up and to contact with the rear of the scraper, push through the hole, boost out of the hole, and maneuver to match up to the next scraper coming through the hole.

Output of scrapers depends on the following main factors:

i. Size and mechanical condition of the scraper
ii. Hauling distance
iii. Condition of the haul road
iv. Characteristics of soil and work area.
v. Efficiency

Scraper production cycle

The production cycle for a scraper consists of six operations listed below.

- Loading
- Haul travel
- Dumping and spreading ,
- Turning
- Return travel and
- Turning and positioning to pick up another load.

Ts = Load time + haul time+ dump time + turn time +return time +turning to position time.

Loading time is fairly consistent regardless of the scraper size, even though large scrapers carry larger loads they load just as fast as smaller machines. This attributes to the fact that the larger scraper has more horse power and it will be matched with larger push tractor.

Example 2.10

A Cat D631E Series II wheel tractor scraper assisted with a D9R bulldozeris to be used to move dirt about 1280m to build a detention pond at the entry of subdivision. The D9 has ripped the soil in the area to be excavated about 0.5m deep. The D9 is to push the scraper until it is out of the hole. Once full, the scraper's average haul speed will be around 15km/h. The return route is about 1350m and the average return speed will be around 22km/h. The rated heaped capacity of the D631 is 31Lcy. The estimated load time according to the performance manual is 0.6 min. The estimated dump time is about 0.7min. What is the work hour productivity if the operator works 50 min per 60-min hour?

Solution:

a. Work hour production = [(rated capacity) *(operational efficiency)]/cycletime

Haul time = travel distance / travel speed =(1280m/15000m/hr *60min)= 5.12min.

Backtrack(return)time = 1350m/[(22000m/hr)*60min =3.68 min

Cycletime = load+ haul +dump + return

= 0.6 min +5.12 min +0.7 min +3.68 min = 10.10 min/cycle

Production =[(31 Lcy)(50 min/h)]/10.10 min/cycle = **153.47lcy/h**

2.8 Productivity of Grading Equipment

Graders are usually set up to run in linear or rectangular patterns. Production is measured in area covered in a certain amount of time (square feet per hour, cubic feet per hour).In road base construction, the grader is typically the last major earthmoving equipment used during compaction.

Grader production for road maintenance is pretty much linear. For mass earthmovingprojects, grader production must be matched to production of other equipment (usually scrapers or dump trucks) in the equipment package dumping material to be spread in lifts. Linear grading productivity is estimated using.

Output of a motor grader depends upon the following main factors:

i. Size and mechanical condition of the motor grader
ii. Size of the blade
iii. Speed of travel
iv. Characteristics of soil being handled
v. Efficiency of the operator

In the majority of the cases, as the grader has multiple applications, the computation of its productivity is not always possible. It can, however, be estimated, case by case.

Method-1

Average actual productivity for **levelling and spreading** can be computed as follow

$Q_a = B \times L \times f_N \times f_Z \times 60/T$ [m^2/hr]

$B = l \times \cos A$

Where, B = width per strip with due consideration of over lapping

l = length of blade

A = Angle of blade with respect to the axis (refer Table 4.1)

L = lift thickness after compaction

f_N = factor to take care of site conditions, operator effectiveness (refer Table 4.2)

f_Z = time factor (refer Table 4.3)

T = Cycle time, $T = 0.06\sum P/v$

P = number of passes

V = forward and back ward average speed

Table 4.1 Blade angle for different operation

Type of earth/operation	Angle A in degrees
Normal	30

Hard earth	45
Loose and light material	20
Scarify, mix and spreading across	30-50
Fine levelling and spreading along	0-30

Table 4.2 f_N- factor to take care of site conditions and operator effectiveness				
	Very good	good	Average	Poor
Site condition	0.95	0.9	0.8	0.6
Operator effectiveness	1	0.85	0.75	0.6

Table 4.3.A Average speed for different operation	
Type of operation	**Speed in Km/hr**
Road maintenance	9-Apr
Mix	8
Spread	9-Apr
Sub base work	8-Apr
Fine levelling	22-Sep
Cutting slopes	9-Jul
Ditching	8-Apr
Back ward and idle non operational speed	10-Vmax as per manufacturers spec

Method-2

Grader production is also calculated as area covered by motor grader per hour.

$$A = B \times Vav \times \eta$$

Where, B = width per strip (m)

= 0.8 x l x cos A

l = length of blade

A = Angle with respect to axis

V_{av} = Average speed (m/hr)

η = efficiency

Time required to complete a roadway project can be calculated by

$$T = \frac{\text{Number of passes x Distance (Km)}}{\text{Average speed (Km/hr) x Efficiency factor}}$$

Method-3 (CAT Performance handbook)

One method expresses a motor grader's production in relation to the area covered by the moldboard.

A = S x (Le – Lo) x 1000 x E (Metric)

A = S x (Le – Lo) x 5280 x E (English)

where, A = Hourly operating area (m2/h or ft2/h)

S = Operating speed (Km/h or mph)

Le = Effective blade length (m or ft)

Lo = Width of overlap (m or ft)

E = Efficiency

Operating speeds:

Typical operating speeds by operation are provided as follow

Finish Grading:	0-4 km/h	(0-2.5 mph)
Heavy Blading:	0-9 km/h	(0-6 mph)
Ditch Repair:	0-5 km/h	(0-3 mph)
Ripping:	0-5 km/h	(0-3 mph)
Road Maintenance:	5-16 km/h	(3-9.5 mph)
Haul Road Maintenance:	5-16 km/h	(3-9.5 mph)
Snow Plowing:	7-21 km/h	(4-13 mph)
Snow Winging:	15-28 km/h	(9-17 mph)

Effective blade length: Since the moldboard is usually angled when moving material, an effective blade length must be computed to account for this angle. This is the actual width of material swept by the moldboard.

Moldboard Length, m (ft)	Effective Length, m (ft) 30 degree blade angle	Effective Length, m (ft) 45 degree blade angle
3.658 (12)	3.17 (10.4)	2.59 (8.5)
3.962 (13)	3.43 (11.3)	2.80 (9.2)
4.267 (14)	3.70 (12.1)	3.02 (9.9)
4.877 (16)	4.22 (13.9)	3.45 (11.3)
7.315 (24)	6.33 (20.8)	5.17 (17.0)

Width overlap: The width of overlap is generally 0.6 m (2.0 ft). This overlap accounts for the need to keep the tires out of the windrow on the return pass.

Job Efficiency: Job efficiencies vary based on job conditions, operator skill, etc. A good estimation for efficiency is approximately 0.70 to 0.85, but actual operating conditions should be used to determine the best value.

Example 2.11

A Volvo G740B motor grader with a 3.2m blade is to be used to knock down dirt on a 15m wide X 2250m long road base area. The effective grading width is 2.77m. The average speed will be around 6km/hr. If the number of passes required to reach the desired density of the earth is two, answer the following questions.

a. What is the work hour productivity of the grader based on area method, if the operator works 50 min per 60-min?

b. How long will it take to grade the road base?

Solution:

Assuming overlap width to =0.6m

a. probable hourly production= [V*(Le-Lo)*1000*E]/n

= [6km/hr*(2.77-0.6)**1000*0.83]/2

= **5403.3m2/hr**

b. The total area of the road = 15m X 2250m= **33750m2**

   Time required = 33750m2*/5403.3m2/hr = **6.25hr.**

2.9 Truck Production

Truck production is similar to the other earthmoving equipment cycles. Trucks however are typically dependent on another piece of equipment for loading. Truckloads are rated by volume and weight. Trucks must be permitted to operate on public highways and streets. Production cycles have fixed and variable times. Typical cycle fixed times include loading, dumping, and required spotting times. It should be noted that the loading time is the time required by the piece of equipment loading the truck. The loading time equals number of cycles required to load the truck times the estimated cycle time. The number of loader cycles to fill a truck equals volume of the truck divided by the volume of the loader bucket per cycle. Trucks are usually loaded by front-end loaders or excavators. Spotting to load or dump and wait or delay times are influenced by job conditions, work setup, and management of the process.

The most important consideration when matching excavator and truck is finding equipment having compatible capacities. Matched capacities yield maximum loading efficiency.

The following steps can be adopted in calculating truck production

Step-1 Bucket loads (Number of bucket)

The first step in analyzing truck production is to determine the number of excavator bucket loads it takes to load the truck.

$$\boxed{\text{Bucket loads} = \frac{\text{Truck capacity}}{\text{Loader Bucket capacity}}}$$

Bucket loads must be an integer number.Check load weight against gravimetric capacity of the haul unit.

Step-2 Load time and truck load volume

In calculating the time required for a haul unit to make one complete cycle, it is customary to break the cycle down into fixed and variable components.

Fixed time: spot time (moving the unit position to begin loading), load time, maneuver time, and dump time. Fixed time can usually be closely estimated for a particular type of operation.

Variable time: represents the travel time required for a unit to haul material to the unloading site and return.

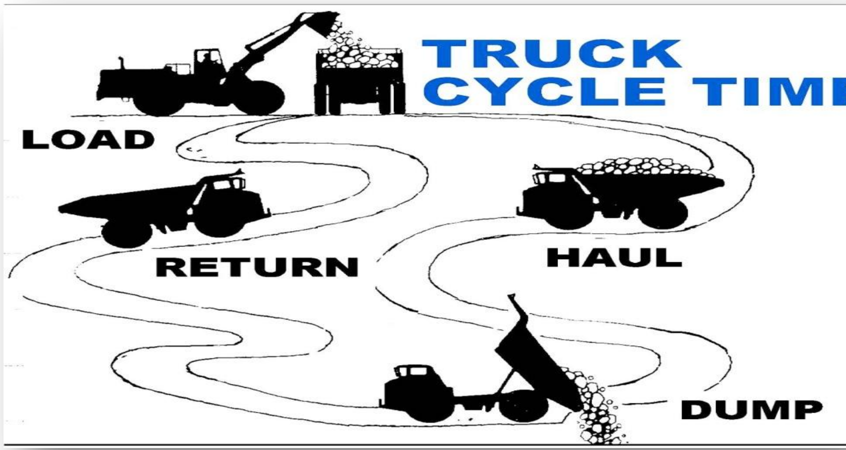


Figure 2.4 Truck cycle time

Next lower integer: for the case where the number of bucket loads is rounded down to an integer lower than the balance number of loads or reduced because of job conditions

Load time = Number of bucket loads x Bucket cycle time

Truck load $_{LI}$ (Volumetric) = Number of bucket loads x Bucket Volume

Next Higher integer: If the division of truck cargo body volume by the bucket volume is rounded to the next higher integer that higher number of bucket is placed on the truck, excess material will spill of the truck. In such case:

Load time = Number of bucket loads x Bucket cycle time

Truck load $_{HI}$ (Volumetric) = Truck volumetric capacity

Gravimetric check: always check the load weight against the gravimetric capacity of the truck.

Truck load (Gravimetric) < Number of bucket loads x Bucket Volume

Step-3 Haul Time

Hauling should be at highest safe speed and in the proper gear.

Travel time will depend on

- The vehicle's weight and power,
- The condition of the haul road,
- The grades encountered, and
- The altitude above sea level

A. Rolling Resistance

The resistance that a vehicle encounters in traveling over a surface is made up of two components, rolling resistance and grade resistance.

Total Resistance = Grade resistance + Rolling resistance

B. Grade Resistance

Grade resistance represents that component of vehicle weight which acts parallel to an inclined surface.

- When the vehicle is traveling up a grade, grade resistance is positive.
- When traveling downhill, grade resistance is negative

$$\boxed{\text{Grade Resistance Factor (kg/t)} = 10 \text{ x Grade (\%)}}$$

C. Effective Grade

The total resistance to movement of a vehicle (the sum of its rolling resistance and grade resistance) may be expressed in pounds or kilograms.

However, a somewhat simpler method for expressing total resistance is to state it as a grade (%), which would have a grade resistance equivalent to the total resistance actually encountered.

$$\boxed{\text{Effective Grade (\%)} = \text{Grade (\%)} + \frac{\text{Rolling Resistance Factor (kg/t)}}{10}}$$

D. *Effect of Altitude*

All internal combustion engines ***lose power as their elevation above sea level increases*** because of the decreased density of air at higher elevations.

F. Estimating Travel Time

The first method for estimating travel time over a haul route is to use Equations

$$\boxed{T_T = \frac{\text{Length of the Road Section (km)}}{\text{Average Speed (km/hr)}} = \frac{L \text{ (km)}}{V_{avg} \text{ (km/hr)}}}$$

$$\boxed{V_{max} = \frac{P_{mo}}{(G_P + G_E) \text{ x } \sum R} \text{ x } \eta}$$

$$V_{avg} = V_{max} \times S_f$$

Where P_{mo} = Power output of motor [KW]

G_P = Payload (KN)

G_E = Empty Weight of Hauler (KN)

$\sum R$ = Effective Grade

η = Efficiency

Step-4 Dump Time

Dump time will depend on the type of hauling unit and congestion in the dump area. Is the dump area crowded with support equipment?

- Rear dumps must be spotted before dumping. Total dump time can exceed 2 minutes.
- Bottom dump units dump while moving.

Turn and Dum Times (Min.)

Conditions	Bottom Dump	End Dump
Favorable	0.3	0.7
Average	0.6	1.0
Unfavorable	1.5	1.5

Step-5 Return Time

Based on the empty vehicle weight, the rolling and grade resistance from the dump point to the loading area, return travel time can be estimated using the truck manufacturers performance chart.

$$T_R = \frac{\text{Length of the Road Section (km)}}{\text{Average Speed (km/hr)}} = \frac{L\ (\text{km})}{V_{avg}\ (\text{km/hr})}$$

Step-6 Truck cycle time

The cycle time of a truck is the sum of the load time, haul time, dump time and the return time.

$$Truck\ time = Load_{Time} + Haul_{Time} + Dump_{Time} + Return_{Time}$$

Step-7 Number of Trucks Required

The number of trucks required to keep the loading equipment working at capacity is:

$$\boxed{\text{Balanced number of trucks} = \frac{\text{Truck cycle time (min)}}{\text{Excavator cycle time (min)}}}$$

Step-8 Production

The number of trucks must be an integer number.

Integer lower than balance number: If an integer number of trucks lower than the result obtained from the above equationis chosen, then the trucks will control the production.

$$\boxed{\begin{matrix}\text{Production}\\ \text{(lcy/hr)}\end{matrix} = \begin{matrix}\text{Truck}\\ \text{load (lcy)}\end{matrix} \times \begin{matrix}\text{Number}\\ \text{of trucks}\end{matrix} \times \frac{60\text{ min}}{\text{Truck cycle time (min)}}}$$

Integer greater than balance number: If an integer number of trucks greater than the balanced number of truckis chosen, then production is controlled by the loading equipment.

$$\boxed{\begin{matrix}\text{Production}\\ \text{(lcy/hr)}\end{matrix} = \begin{matrix}\text{Truck}\\ \text{load (lcy)}\end{matrix} \times \frac{60\text{ min}}{\text{Excavator cycle time (min)}}}$$

As a rule it is better to never keep the loading equipment waiting. If there is not a sufficient number of haul trucks, there will be a loss in production.Truck bunching or queuing will reduce production 10 to 20% even when there is a perfect match between excavator capability and number of trucks.

Step-9 Efficiency

The production calculated with the above equation is based on a 60-min working hour. This production should be adjusted by an efficiency factor.Longer haul distances usually result in better driver efficiency.Other critical elements affecting efficiency are bunchingand equipment condition.

$$\text{Adjusted production} = \text{Production} \times \frac{\text{Working time (min/hour)}}{60 \text{ min}}$$

Example 2.12

A Cat 320C excavator equipped with a 1.96 lcy heaped bucket is used to dig in sandy clay soil. It takes about 0.33 min per bucket load dumped into a fleet of Cat D30D articulated trucks. Each truck carries a heaped capacity of 21.6 lcy. It takes about 5 min to haul and dump the load, return and position for reloading:

a. How long does it take to load one D30D? (Assume the bucket fill factor =1.0)

b. How much dirt can be hauled in 1 work hour by one D30D?

c. How many D30D articulated trucks will the 320C excavator support?

Solution:

a. No of bucket required to load the truck = Vt/Vex = 21.6lcy/1.96lcy=11.02 round to 11

Time to load the truck = 11*0.33min= **3.63min**.

b. Probable hourly production = [Vt*Ff *E]/tcy,tcy = 3.63min +5min = 8.63min.

   = [21.6*1.0*(50min/60min)*60min]/8.63min =**125.15lcy/hr**

c. No of truck = truck cycle time/excavator loading time = 8.63min/3.63min = 2.38 round to **=2 trucks.**

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1. Construction planning, equipment and method, Robert. L Peurifoy, Clifford J.Schexnayder, AviadShapira, 7th edition, McGraw Hill Publishers.
2. Construction equipment management for engineers, estimators, and owners, Gransberg, Popescu& Ryan, Taylor & Francis Group, 2006.