4

Loading and Hauling

4–1 ESTIMATING EQUIPMENT TRAVEL TIME

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.

$$\text{Cycle time} = \text{Fixed time} + \text{Variable time} \tag{4–1}$$

Fixed time represents those components of cycle time other than travel time. It includes spot time (moving the unit into 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. As you would expect, 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. This section presents methods for calculating a vehicle's resistance to movement, its maximum speed, and its travel time. Methods for estimating fixed times are given in Sections 4–2 to 4–5, which describe specific types of hauling equipment.

Rolling Resistance

To determine the maximum speed of a vehicle in a specific situation, it is necessary to determine the total resistance to movement of the vehicle. The resistance that a vehicle encounters in traveling over a surface is made up of two components, rolling resistance and grade resistance.

$$\text{Total resistance} = \text{Grade resistance} + \text{Rolling resistance} \tag{4–2}$$

Resistance may be expressed in either pounds per ton of vehicle weight (kilograms per metric ton) or in pounds (kilograms). To avoid confusion, the term *resistance factor* will be used in this chapter to denote resistance in lb/ton (kg/t). *Rolling resistance* is primarily due to tire flexing and penetration of the travel surface. The rolling resistance factor for a rubber-tired vehicle equipped with conventional tires moving over a hard, smooth, level surface has been found to be about 40 lb/ton of vehicle weight (20 kg/t). For vehicles equipped with radial tires, the rolling resistance factor may be as low as 30 lb/ton (15 kg/t). It has been found that

Table 4–1 Typical values of rolling resistance factor

Type of Surface	Rolling Resistance Factor	
	lb/ton	*kg/t*
Concrete or asphalt	40 (30)*	20 (15)
Firm, smooth, flexing slightly under load	64 (52)	32 (26)
Rutted dirt roadway, 1–2 in. penetration	100	50
Soft, rutted dirt, 3–4 in. penetration	150	75
Loose sand or gravel	200	100
Soft, muddy, deeply rutted	300–400	150–200

*Values in parentheses are for radial tires.

the rolling resistance factor increases about 30 lb/ton (15 kg/t) for each inch (2.5 cm) of tire penetration. This leads to the following equation for estimating rolling resistance factors:

$$\text{Rolling resistance factor (lb/ton)} = 40 + (30 \times \text{in. penetration}) \qquad \textbf{(4–3}\textbf{\textit{A}}\textbf{)}$$

$$\text{Rolling resistance factor (kg/t)} = 20 + (6 \times \text{cm penetration}) \qquad \textbf{(4–3}\textbf{\textit{B}}\textbf{)}$$

The rolling resistance in pounds (kilograms) may be found by multiplying the rolling resistance factor by the vehicle's weight in tons (metric tons). Table 4–1 provides typical values for the rolling resistance factor in construction situations.

Crawler tractors may be thought of as traveling over a road created by their own tracks. As a result, crawler tractors are usually considered to have no rolling resistance when calculating vehicle resistance and performance. Actually, of course, the rolling resistance of crawler tractors does vary somewhat between different surfaces. However, the standard method for rating crawler tractor power (drawbar horsepower) measures the power actually produced at the hitch when operating on a standard surface. Thus the rolling resistance of the tractor over the standard surface has already been subtracted from the tractor's performance. Although a crawler tractor is considered to have no rolling resistance, when it tows a wheeled vehicle (such as a scraper or compactor) the rolling resistance of the towed vehicle must be considered in calculating the total resistance of the combination.

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. The exact value of grade resistance may be found by multiplying the vehicle's weight by the sine of the angle that the road surface makes with the horizontal. However, for the grades usually encountered in construction, it is sufficiently accurate to use the approximation of Equation 4–4. That is, a 1% grade (representing a rise of 1 unit in 100 units of horizontal distance) is considered to have a grade resistance equal to 1% of the vehicle's weight. This corresponds to a grade resistance factor of 20 lb/ton (10 kg/t) for each 1% of grade.

$$\text{Grade resistance factor (lb/ton)} = 20 \times \text{grade (\%)} \qquad \textbf{(4–4}\boldsymbol{A}\textbf{)}$$

$$\text{Grade resistance factor (kg/t)} = 10 \times \text{grade (\%)} \qquad \textbf{(4–4}\boldsymbol{B}\textbf{)}$$

Grade resistance (lb or kg) may be calculated using Equation 4–5 or 4–6.

$$\text{Grade resistance (lb)} = \text{Vehicle weight (tons)} \times \text{Grade resistance factor (lb/ton)} \qquad \textbf{(4–5}\boldsymbol{A}\textbf{)}$$

$$\text{Grade resistance (kg)} = \text{Vehicle weight (t)} \times \text{Grade resistance factor (kg/t)} \qquad \textbf{(4–5}\boldsymbol{B}\textbf{)}$$

$$\text{Grade resistance (lb)} = \text{Vehicle weight (lb)} \times \text{Grade} \qquad \textbf{(4–6}\boldsymbol{A}\textbf{)}$$

$$\text{Grade resistance (kg)} = \text{Vehicle weight (kg)} \times \text{Grade} \qquad \textbf{(4–6}\boldsymbol{B}\textbf{)}$$

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. This method of expressing total resistance is referred to as *effective grade, equivalent grade,* or *percent total resistance* and is often used in manufacturers' performance charts. Effective grade may be easily calculated by use of Equation 4–7.

$$\text{Effective grade (\%)} = \text{Grade (\%)} + \frac{\text{Rolling resistance factor (lb/ton)}}{20} \qquad \textbf{(4–7}\boldsymbol{A}\textbf{)}$$

$$\text{Effective grade (\%)} = \text{Grade (\%)} + \frac{\text{Rolling resistance factor (kg/t)}}{10} \qquad \textbf{(4–7}\boldsymbol{B}\textbf{)}$$

EXAMPLE 4–1

A wheel tractor-scraper weighing 100 tons (91 t) is being operated on a haul road with a tire penetration of 2 in. (5 cm). What is the total resistance (lb and kg) and effective grade when (a) the scraper is ascending a slope of 5%; (b) the scraper is descending a slope of 5%?

SOLUTION

$$\text{Rolling resistance factor} = 40 + (30 \times 2) = 100 \text{ lb/ton} \qquad \text{(Eq 4–3}A\text{)}$$

$$[= 20 + (6 \times 5) = 50 \text{ (kg/t)}] \qquad \text{(Eq 4–3}B\text{)}$$

$$\text{Rolling resistance} = 100 \text{ (lb/ton)} \times 100 \text{ (tons)} = 10{,}000 \text{ lb}$$

$$[= 50 \text{ (kg/t)} \times 91 \text{ (t)} = 4550 \text{ kg}]$$

$$\text{(a) Grade resistance} = 100 \text{ (tons)} \times 2000 \text{ (lb/ton)} \times 0.05 \qquad \text{(Eq 4–6}A\text{)}$$

$$= 10{,}000 \text{ lb}$$

$$[= 91 \text{ (t)} \times 1000 \text{ (kg/t)} \times 0.05 = 4550 \text{ kg}] \text{ (Eq 4–6}B\text{)}$$

$$\text{Total resistance} = 10{,}000 \text{ lb} + 10{,}000 \text{ lb} = 20{,}000 \text{ lb} \qquad \text{(Eq 4–2)}$$

$$[= 4550 \text{ kg} + 4550 \text{ kg} = 9100 \text{ kg}]$$

$$\text{Effective grade} = 5 + \frac{100}{20} = 10\% \qquad \text{(Eq 4–7}A\text{)}$$

$$\text{(b) Grade resistance} = 100\text{ (tons)} \times 2000\text{ (lb/ton)} \times (-0.05) \qquad \text{(Eq 4–6}A\text{)}$$

$$= -10{,}000\text{ lb}$$

$$[= 91\text{ (t)} \times 1000\text{ (kg/t)} \times (-0.05) = -4550\text{ kg}] \text{ (Eq 4–6}B\text{)}$$

$$\text{Total resistance} = -10{,}000\text{ lb} + 10{,}000\text{ lb} = 0\text{ lb}$$

$$[= -4550\text{ kg} + 4550\text{ kg} = 0\text{ kg}] \qquad \text{(Eq 4–2)}$$

$$\text{Effective grade} = -5 + \frac{100}{20} = 0\% \qquad \text{(Eq 4–7}A\text{)}$$

$$\left[= -5 + \frac{50}{10} = 0\%\right] \qquad \text{(Eq 4–7}B\text{)}$$

EXAMPLE 4–2

A crawler tractor weighing 80,000 lb (36 t) is towing a rubber-tired scraper weighing 100,000 lb (45.5 t) up a grade of 4%. What is the total resistance (lb and kg) of the combination if the rolling resistance factor is 100 lb/ton (50 kg/t)?

SOLUTION

$$\text{Rolling resistance (neglect crawler)} = \frac{100{,}000\text{ (lb)}}{2000\text{ (lb/ton)}} \times 100\text{ (lb/ton)} = 5000\text{ lb}$$

$$[= 45.5\text{ (t)} \times 50\text{ (kg/t)} = 2275\text{ kg}]$$

$$\text{Grade resistance} = 180{,}000 \times 0.04 = 7200\text{ lb} \qquad \text{(Eq 4–6}A\text{)}$$

$$[= 81.5 \times 1000\text{ kg/t} \times 0.04 = 3260\text{ kg}] \qquad \text{(Eq 4–}B\text{)}$$

$$\text{Total resistance} = 5000 + 7200 = 12{,}200\text{ lb} \qquad \text{(Eq 4–2)}$$

$$[= 2275 + 3260 = 5535\text{ kg}]$$

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. There is some variation in the performance of two-cycle and four-cycle naturally aspirated and turbocharged diesel engines. However, engine power decreases approximately 3% for each 1000 ft (305 m) increase in altitude above the maximum altitude at which full rated power is delivered. Turbocharged engines are more efficient at higher altitude than are naturally aspirated engines and may deliver full rated power up to an altitude of 10,000 ft (3050 m) or more.

Manufacturers use a *derating factor* to express percentage of reduction in rated vehicle power at various altitudes. Whenever possible, use the manufacturer's derating table for estimating vehicle performance. However, when derating tables are not available, the derating factor obtained by the use of Equation 4–8 is sufficiently accurate for estimating the performance of naturally aspirated engines.

$$\text{Derating factor}\,(\%) = 3 \times \left[\frac{\text{Altitude (ft)} - 3000^*}{1000}\right] \qquad \textbf{(4–8A)}$$

$$\text{Derating factor}\,(\%) = \frac{\text{Altitude (m)} - 915^*}{102} \qquad \textbf{(4–8B)}$$

The percentage of rated power available is, of course, 100 minus the derating factor. The use of derating factors in determining maximum vehicle power is illustrated in Example 4–3.

Effect of Traction

The power available to move a vehicle and its load is expressed as *rimpull* for wheel vehicles and *drawbar pull* for crawler tractors. Rimpull is the pull available at the rim of the driving wheels under rated conditions. Since it is assumed that no slippage of the tires on the rims will occur, this is also the power available at the surface of the tires. Drawbar pull is the power available at the hitch of a crawler tractor operating under standard conditions. Operation at increased altitude may reduce the maximum pull of a vehicle, as explained in the previous paragraph. Another factor limiting the usable power of a vehicle is the maximum traction that can be developed between the driving wheels or tracks and the road surface. Traction depends on the coefficient of traction and the weight on the drivers as expressed by Equation 4–9. This represents the maximum pull that a vehicle can develop, regardless of vehicle horsepower.

$$\text{Maximum usable pull} = \text{Coefficient of traction} \times \text{Weight on drivers} \qquad \textbf{(4–9)}$$

For crawler tractors and all-wheel-drive rubber-tired equipment, the weight on the drivers is the total vehicle weight. For other types of vehicles, consult the manufacturer's specifications to determine the weight on the drivers. Typical values of coefficient of traction for common surfaces are given in Table 4–2.

Table 4–2 Typical values of coefficient of traction

Type of Surface	Rubber Tires	Tracks
Concrete, dry	0.90	0.45
Concrete, wet	0.80	0.45
Earth or clay loam, dry	0.60	0.90
Earth or clay loam, wet	0.45	0.70
Gravel, loose	0.35	0.50
Quarry pit	0.65	0.55
Sand, dry, loose	0.25	0.30
Sand, wet	0.40	0.50
Snow, packed	0.20	0.25
Ice	0.10	0.15

*Substitute maximum altitude for rated performance, if known.

EXAMPLE 4–3

A four-wheel-drive tractor weighs 44,000 lb (20,000 kg) and produces a maximum rimpull of 40,000 lb (18160 kg) at sea level. The tractor is being operated at an altitude of 10,000 ft (3050 m) on wet earth. A pull of 22,000 lb (10,000 kg) is required to move the tractor and its load. Can the tractor perform under these conditions? Use Equation 4–8 to estimate altitude deration.

SOLUTION

$$\text{Derating factor} = 3 \times \left[\frac{10{,}000 - 3000}{1000}\right] = 21\% \quad (\text{Eq 4–8}A)$$

$$\left[= \frac{3050 - 915}{102} = 21\%\right] \quad (\text{Eq 4–8}B)$$

$$\text{Percent rated power available} = 100 - 21 = 79\%$$

$$\text{Maximum available power} = 40{,}000 \times 0.79 = 31{,}600 \text{ lb}$$

$$[= 18160 \times 0.79 = 14346 \text{ kg}]$$

$$\text{Coefficient of traction} = 0.45 \quad (\text{Table 4–2})$$

$$\text{Maximum usable pull} = 0.45 \times 44{,}000 = 19{,}800 \text{ lb} \quad (\text{Eq 4–9})$$

$$[= 0.45 \times 20000 = 9000 \text{ kg}]$$

Because the maximum pull as limited by traction is less than the required pull, the tractor *cannot perform under these conditions.* For the tractor to operate, it would be necessary to reduce the required pull (total resistance), increase the coefficient of traction, or increase the tractor's weight on the drivers.

Use of Performance and Retarder Curves

Crawler tractors may be equipped with direct-drive (manual gearshift) transmissions. The drawbar pull and travel speed of this type of transmission are determined by the gear selected. For other types of transmissions, manufacturers usually present the speed versus pull characteristics of their equipment in the form of performance and retarder charts. A *performance chart* indicates the maximum speed that a vehicle can maintain under rated conditions while overcoming a specified total resistance. A *retarder chart* indicates the maximum speed at which a vehicle can descend a slope when the total resistance is negative without using brakes. Retarder charts derive their name from the vehicle retarder, which is a hydraulic device used for controlling vehicle speed on a downgrade.

Figure 4–1 illustrates a relatively simple performance curve of the type often used for crawler tractors. Rimpull or drawbar pull is shown on the vertical scale and maximum vehicle speed on the horizontal scale. The procedure for using this type of curve is to first calculate the required pull or total resistance of the vehicle and its load (lb or kg). Then enter

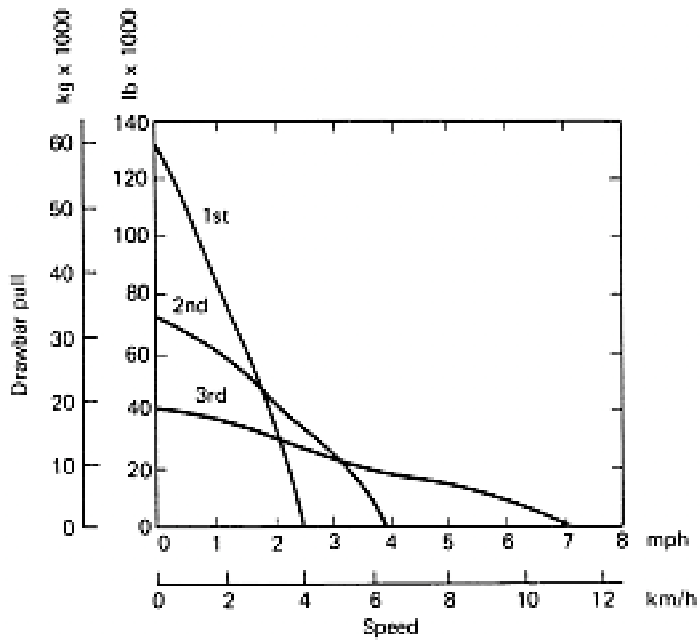

Figure 4–1 Typical crawler tractor performance curve.

the chart on the vertical scale with the required pull and move horizontally until you intersect one or more gear performance curves. Drop vertically from the point of intersection to the horizontal scale. The value found represents the maximum speed that the vehicle can maintain while developing the specified pull. When the horizontal line of required pull intersects two or more curves for different gears, use the point of intersection farthest to the right, because this represents the maximum speed of the vehicle under the given conditions.

EXAMPLE 4–4

Use the performance curve of Figure 4–1 to determine the maximum speed of the tractor when the required pull (total resistance) is 60,000 lb (27,240 kg).

SOLUTION

Enter Figure 4–1 at a drawbar pull of 60,000 lb (27,240 kg) and move horizontally until you intersect the curves for first and second gears. Read the corresponding speeds of 1.0 mi/h (1.6 km/h) for second gear and 1.5 mi/h (2.4 km/h) for first gear. The maximum possible speed is therefore 1.5 mi/h (2.4 km/h) in first gear.

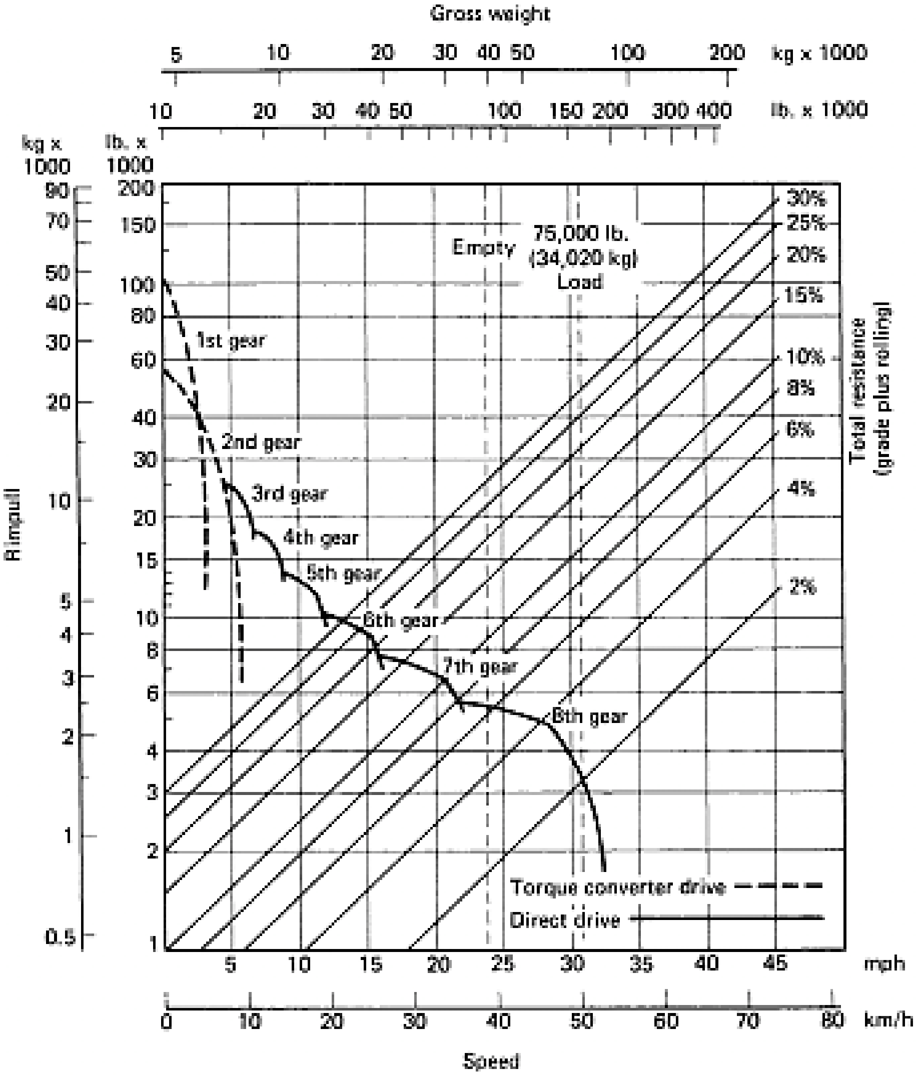

Figure 4–2 Wheel scraper performance curve. (Courtesy of Caterpillar Inc.)

Figure 4–2 represents a more complex performance curve of the type frequently used by manufacturers of tractor-scrapers, trucks, and wagons. In addition to curves of speed versus pull, this type of chart provides a graphical method for calculating the required pull (total resistance). To use this type of curve, enter the top scale at the actual weight of the vehicle (empty or loaded as applicable). Drop vertically until you intersect the diagonal line corresponding to the percent total resistance (or effective grade), interpolating as necessary. From this point move horizontally until you intersect one or more performance curves. From the point of intersection, drop vertically to find the maximum vehicle speed.

When altitude adjustment is required, the procedure is modified slightly. In this case, start with the gross weight on the top scale and drop vertically until you intersect the total resistance curve. Now, however, move horizontally all the way to the left scale to read the required pull corresponding to vehicle weight and effective grade. Next, divide the required pull by the quantity "1 − derating factor (expressed as a decimal)" to obtain an adjusted required pull. Now, from the adjusted value of required pull on the left scale move horizontally to intersect one or more gear curves and drop vertically to find the maximum vehicle speed. This procedure is equivalent to saying that when a vehicle produces only one-half of its rated power due to altitude effects, its maximum speed can be found from its standard performance curve by doubling the actual required pull. The procedure is illustrated in Example 4–5.

EXAMPLE 4–5

Using the performance curve of Figure 4–2, determine the maximum speed of the vehicle if its gross weight is 150,000 lb (68,000 kg), the total resistance is 10%, and the altitude derating factor is 25%.

SOLUTION

Start on the top scale with a weight of 150,000 lb (68,000 kg), drop vertically to intersect the 10% total grade line, and move horizontally to find a required pull of 15,000 lb (6800 kg) on the left scale. Divide 15,000 lb (6800 kg) by 0.75 (1 − derating factor) to obtain an adjusted required pull of 20,000 lb (9080 kg). Enter the left scale at 20,000 lb (9080 kg) and move horizontally to intersect the first, second, and third gear curves. Drop vertically from the point of intersection with the third gear curve to find a maximum speed of 6 mi/h (10 km/h).

Figure 4–3 illustrates a typical retarder curve. In this case, it is the retarder curve for the tractor-scraper whose performance curve is shown in Figure 4–2. The retarder curve is read in a manner similar to the performance curve. Remember, however, that in this case the vertical scale represents *negative* total resistance. After finding the intersection of the vehicle weight with effective grade, move horizontally until you intersect the retarder curve. Drop vertically from this point to find the maximum speed at which the vehicle should be operated.

Estimating Travel Time

The maximum speed that a vehicle can maintain over a section of the haul route cannot be used for calculating travel time over the section, because it does not include vehicle acceleration and deceleration. One method for accounting for acceleration and deceleration is to multiply the maximum vehicle speed by an average speed factor from Table 4–3 to obtain an average vehicle speed for the section. Travel time for the section is then found by dividing the section length by the average vehicle speed. When a section of the haul

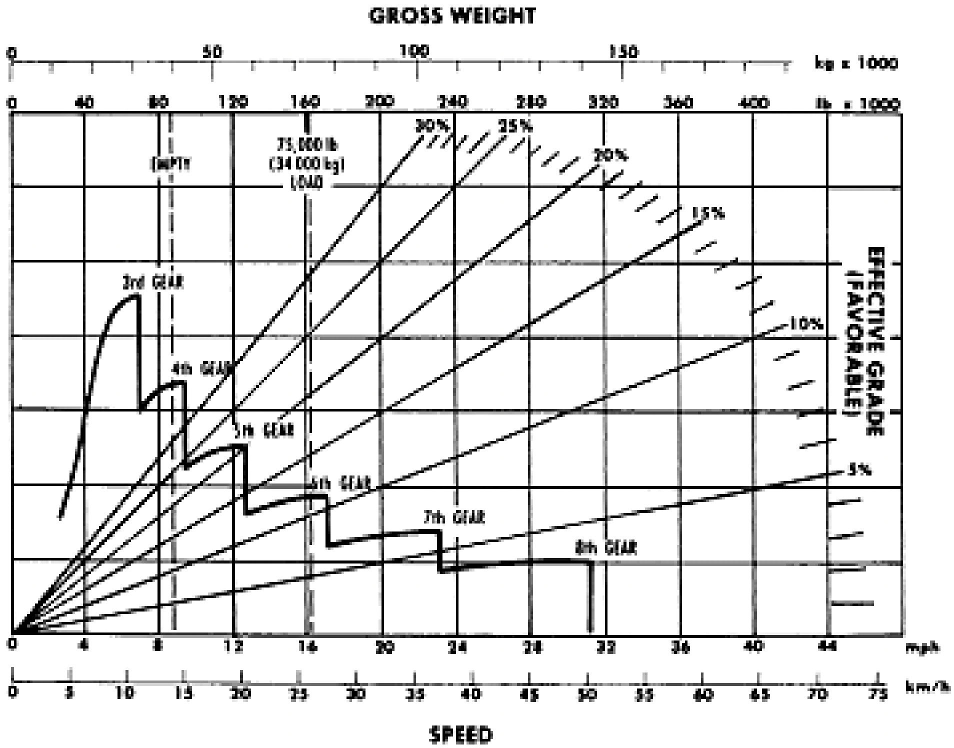

Figure 4–3 Wheel scraper retarder curve. (Courtesy of Caterpillar Inc.)

Table 4–3 Average speed factors

Length of Haul Section		Starting from 0 or Coming to a Stop	Increasing Maximum Speed from Previous Section	Decreasing Maximum Speed from Previous Section
ft	*m*			
150	46	0.42	0.72	1.60
200	61	0.51	0.76	1.51
300	92	0.57	0.80	1.39
400	122	0.63	0.82	1.33
500	153	0.65	0.84	1.29
700	214	0.70	0.86	1.24
1000	305	0.74	0.89	1.19
2000	610	0.86	0.93	1.12
3000	915	0.90	0.95	1.08
4000	1220	0.93	0.96	1.05
5000	1525	0.95	0.97	1.04

route involves both starting from rest and coming to a stop, the average speed factor from the first column of Table 4–3 should be applied twice (i.e., use the square of the table value) for that section.

A second method for estimating travel time over a section of haul route is to use the travel-time curves provided by some manufacturers. Separate travel-time curves are prepared for loaded (rated payload) and empty conditions, as shown in Figures 4–4 and 4–5. As you see, travel time for a section of the haul route may be read directly from the graph given section length and effective grade. However, travel-time curves cannot be used when the effective grade is negative. In this case, the average speed method must be used along with the vehicle retarder curve. To adjust for altitude deration when using travel-time curves, multiply the time obtained from the curve by the quantity "1 + derating factor" to obtain the adjusted travel time.

The use of both the average speed and the travel-time curve method is illustrated in the example problems of this chapter.

4–2 DOZERS

Tractors and Dozers

A tractor equipped with a front-mounted earthmoving blade is known as a *dozer* or *bulldozer*. A dozer moves earth by lowering the blade and cutting until a full blade load of material is obtained. It then pushes the material across the ground surface to the required location. The material is unloaded by pushing it over a cliff or into a hopper or by raising the blade to form a spoil pile.

Both rubber-tired (or wheel) dozers and crawler (or track) dozers are available. Because of their excellent traction and low ground pressure (typically 6 to 9 lb/sq in.; 41 to 62 kPa), crawler dozers (Figure 4–6) are well suited for use in rough terrain or areas of low trafficability. Low-ground-pressure models with extra-wide tracks are available having ground pressures as low as 3 lb/sq in. (21 kPa). Crawler dozers can operate on steeper side slopes and climb greater grades than can wheel dozers. Wheel dozers, on the other hand, operate at higher speed than do crawler dozers. Wheel dozers are also capable of operating on paved roads without damaging the surface. While the wheel tractor's dozing ability is limited somewhat by its lower traction and high ground pressure (25 to 35 lb/sq in.; 172 to 241 kPa), its high ground pressure makes it an effective soil compactor.

Either rubber-tired or crawler tractors may be equipped with attachments other than dozer blades. These include rakes used for gathering up brush and small fallen trees, and plows, rippers, and scarifiers, which are used to break up hard surfaces. Tractors are also used to tow many items of construction equipment, such as compactors, scrapers, and wagons. Towing applications are discussed in succeeding chapters.

Dozers may be equipped with direct-drive, power-shift, or hydrostatic transmissions. *Hydrostatic transmissions* utilize individual hydraulic motors to drive each track. Therefore, the speed of each track may be infinitely varied, forward or reverse. As a result, it is possible for a dozer equipped with a hydrostatic drive to turn in its own length by moving one track forward while the other track moves in reverse.

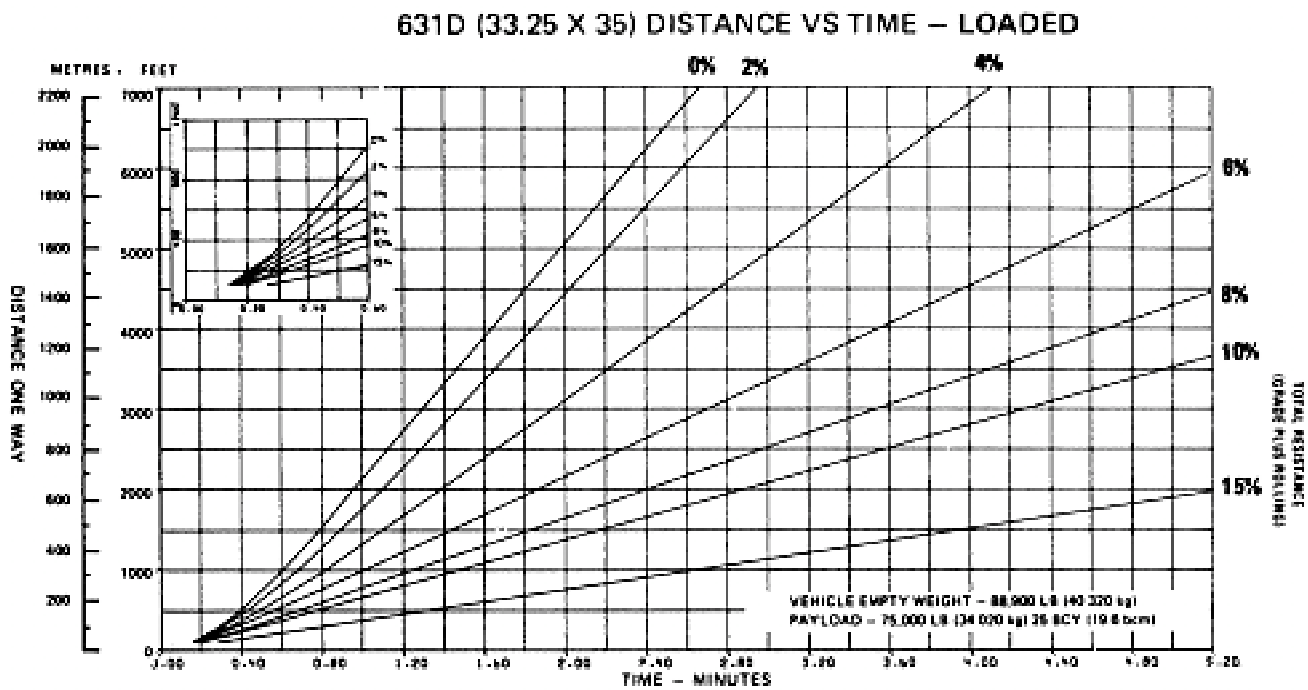

Figure 4–4 Scraper travel time—loaded. (Courtesy of Caterpillar Inc.)

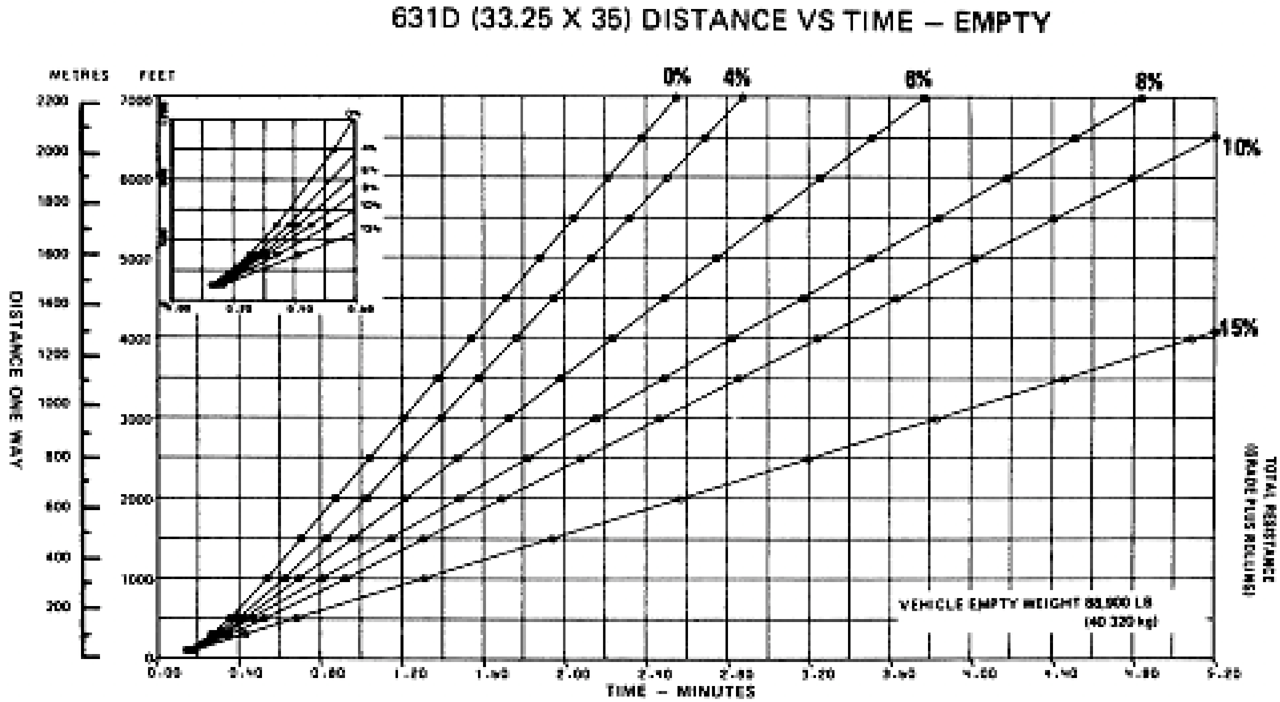

Figure 4–5 Scraper travel time—empty. (Courtesy of Caterpillar Inc.)

Figure 4–6 Crawler tractor dozer. (Courtesy of New Holland Construction)

Dozer Blades

A number of types of dozer blades are available, and the four most common types are illustrated in Figure 4–7. The three types of adjustments that may be made to dozer blades are illustrated in Figure 4–8. Tilting the blade is useful for ditching and breaking up frozen or crusty soils. Pitching the blade forward reduces blade penetration and causes the loosened material to roll in front of the blade, whereas pitching the blade backward increases penetration. Angling the blade is helpful when side-hill cutting, ditching, and moving material laterally. All the blades shown in Figure 4–7 may be tilted except the cushion blade. However, only the angle blade may be angled.

The two indicators of potential dozer performance are based on the ratio of tractor power to blade size. These indicators are horsepower per foot of cutting edge and horsepower

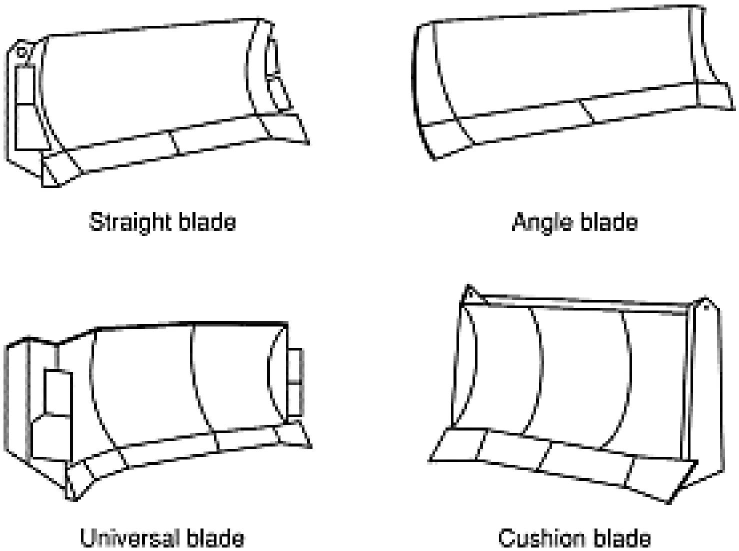

Figure 4–7 Common types of dozer blades.

Figure 4–8 Dozer blade adjustment.

per loose cubic yard. A blade's *horsepower per foot of cutting edge* provides a measure of the blade's ability to penetrate hard soils. The *horsepower per loose cubic yard* rating provides an indication of the blade's ability to push material once the blade is loaded.

The wings on the universal blade (Figure 4–7) enable it to push a large volume of material over long distances. However, its low horsepower per foot of cutting edge and per cubic yard limit its ability to penetrate hard soils or to move heavy materials. The straight blade is considered the most versatile dozer blade. Its smaller size gives it good penetrating and load pushing ability. The ability of angle blades to angle approximately 25° to either side makes them very effective in sidehill cutting, ditching, and backfilling. They may also be used for rough grading and for moving material laterally. The cushion blade is reinforced and equipped with shock absorbers to enable it to push-load scrapers. It may also be used for cleanup of the loading or dumping areas and for general dozing when not push-loading scrapers. Other available types of dozer blades include light-material U-blades, special clearing blades, and ripdozer blades (blades equipped with ripper shanks on each end).

Estimating Dozer Production

The basic earthmoving production equation (Equation 2–1) may be applied in estimating dozer production. This method requires an estimate of the average blade load and the dozer cycle time. There are several methods available for estimating average blade load, including the blade manufacturer's capacity rating, previous experience under similar conditions, and actual measurement of several typical loads. A suggested method for calculating blade volume by measuring blade load is as follows:

- Doze a full blade load, then lift the blade while moving forward on a level surface until an even pile is formed.
- Measure the width of the pile (W) perpendicular to the blade and in line with the inside of each track or wheel. Average the two measurements.
- Measure the height (H) of the pile in a similar manner.
- Measure the length of the pile parallel to the blade.
- Calculate blade volume using Equation 4–10.

$$\text{Blade load (LCY)} = 0.0139 \times H\,(\text{ft}) \times W\,(\text{ft}) \times L\,(\text{ft}) \qquad \textbf{(4–10}A\textbf{)}$$

$$\text{Blade load (LCM)} = 0.375 \times H\,(\text{m}) \times W\,(\text{m}) \times L\,(\text{m}) \qquad \textbf{(4–10}B\textbf{)}$$

Total dozer cycle time is the sum of its fixed cycle time and variable cycle time. *Fixed cycle time* represents the time required to maneuver, change gears, start loading, and dump. Table 4–4 may be used to estimate dozer fixed cycle time. *Variable cycle time* is the time

Table 4–4 Typical dozer fixed cycle times

Operating Conditions	Time (min)
Power-shift transmission	0.05
Direct-drive transmission	0.10
Hard digging	0.15

Table 4–5 Typical dozer operating speeds

Operating Conditions	Speeds
Dozing	
Hard materials, haul 100 ft (30 m) or less	1.5 mi/h (2.4 km/h)
Hard materials, haul over 100 ft (30 m)	2.0 mi/h (3.2 km/h)
Loose materials, haul 100 ft (30 m) or less	2.0 mi/h (3.2 km/h)
Loose materials, haul over 100 ft (30 m)	2.5 mi/h (4.0 km/h)
Return	
100 ft (30 m) or less	Maximum reverse speed in second range (power shift) or reverse speed in gear used for dozing (direct drive)
Over 100 ft (30 m)	Maximum reverse speed in third range (power shift) or highest reverse speed (direct drive)

required to doze and return. Since the haul distance is relatively short, a dozer usually returns in reverse gear. Table 4–5 provides typical operating speeds for dozing and return. Some manufacturers provide dozer production estimating charts for their equipment.

EXAMPLE 4–6

A power-shift crawler tractor has a rated blade capacity of 10 LCY (7.65 LCM). The dozer is excavating loose common earth and pushing it a distance of 200 ft (61 m). Maximum reverse speed in third range is 5 mi/h (8 km/h). Estimate the production of the dozer if job efficiency is 50 min/h.

SOLUTION

$$\text{Fixed time} = 0.05 \text{ min} \qquad \text{(Table 4–4)}$$

$$\text{Dozing speed} = 2.5 \text{ mi/h } (4.0 \text{ km/h}) \qquad \text{(Table 4–5)}$$

$$\text{Dozing time} = \frac{200}{2.5 \times 88} = 0.91 \text{ min}$$

$$\left[= \frac{61}{4 \times 16.7} = 0.91 \text{ min} \right]$$

Note: 1 mi/h = 88 ft/min; 1 km/h = 16.7 m/min

$$\text{Return time} = \frac{200}{5 \times 88} = 0.45 \text{ min}$$

$$\left[= \frac{61}{8 \times 16.7} = 0.45 \text{ min} \right]$$

$$\text{Cycle time} = 0.05 + 0.91 + 0.45 = 1.41 \text{ min}$$

$$\text{Production} = 10 \times \frac{50}{1.41} = 355 \text{ LCY/h}$$

$$\left[= 7.65 \times \frac{50}{1.41} = 271 \text{ LCM/h} \right]$$

Job Management

Some techniques used to increase dozer production include downhill dozing, slot dozing, and blade-to-blade dozing. By taking advantage of the force of gravity, downhill dozing enables blade load to be increased or cycle time to be reduced compared to dozing on the level. Slot dozing utilizes a shallow trench (or slot) cut between the loading and dumping areas to increase the blade capacity that can be carried on each cycle. Under favorable conditions, slot dozing may increase dozer production as much as 50%. The slot dozing technique may be applied to the excavation of large cut areas by leaving uncut sections between slots. These uncut sections are removed after all other material has been excavated. Blade-to-blade dozing involves two dozers operating together with their blades almost touching. This technique results in a combined blade capacity considerably greater than that of two single blades. However, the technique is not efficient for use over short dozing distances because of the extra maneuvering time required. Mechanically coupled side-by-side ($S \times S$) dozers equipped with a single large blade are available and are more productive than are blade-to-blade dozers.

Undercarriages (including track, rollers, idlers, and drive sprockets) are high wear items on all tracked equipment. They are also expensive to buy and maintain. Some operating suggestions for reducing undercarriage wear include the following.

- Make a daily equipment inspection with special attention to the undercarriage. Check the items described in Section 19–6 under PM Indicators.
- Avoid spinning the track by reducing track speed until slippage is minimized.
- Don't operate the equipment at high speed, especially over rough ground or when operating in reverse.
- Use rubber track or rubber track pads when operating on concrete or other hard surfaces.
- During operation, minimize turns. Also, attempt to balance left and right turns and operation up- and down-slope. Alternate directions when it is necessary to traverse slopes.

4–3 LOADERS

A tractor equipped with a front-end bucket is called a *loader, front-end loader,* or *bucket loader.* Both wheel loaders (Figure 4–9) and track loaders (Figure 4–10) are available. Loaders are used for excavating soft to medium-hard material, loading hoppers and haul units, stockpiling material, backfilling ditches, and moving concrete and other construction materials.

Wheel loaders possess excellent job mobility and are capable of over-the-road movement between jobs at speeds of 25 mi/h or higher. While their ground pressure is relatively low and may be varied by the use of different-size tires and by changing inflation pressures, they do not have the all-terrain capability of track loaders. Most modern wheel loaders are *articulated.* That is, they are hinged between the front and rear axles to provide greater maneuverability.

Track loaders are capable of overcoming steeper grades and side slopes than are wheel loaders. Their low ground pressure and high tractive effort enable them to operate in all but the lowest trafficability soils. However, because of their lower speed, their production is less than that of a wheel loader over longer haul distances.

Attachments available for the loader include augers, backhoes, crane booms, dozer and snow blades, and forklifts in addition to the conventional loader bucket. Some models of wheel loader are designed as a combination backhoe and loader. This piece of equipment, often called a *backhoe loader,* is illustrated in Figure 4–11.

Tool Carriers

Tool carriers are similar to wheel loaders but are more versatile because they are equipped with quick coupling devices to accommodate a wide range of attachments or tools. Some

Figure 4–9 Articulated wheel loader with articulated hauler. (Courtesy of Volvo Construction Equipment North America, Inc.)

of the many attachments available include buckets, forks, blades, material handling arms, rotary brooms, asphalt cutters, hooks, augers, and hydraulic hammers.

Skid-Steer Loaders

A *skid-steer loader* (Figure 4–12) is a small wheel loader having rigid axles. It steers by braking the wheels or tracks on one side of the machine while applying power to the other side. A compact track loader is shown in Figure 4–13. These machines usually weigh less than 10,000 lb (4536 kg), have 17 to 115 hp (13 to 86 kW), and have lift capacities of 600 to 6300 lb (272 to 2858 kg). While rubber-tired machines predominate, track machines are also available for operating in muddy or loose soils and on steep slopes. In recent years, skid-steer loaders have become increasingly popular because of their small size, high productivity, and versatility. Like the tool carrier, they can accommodate a number of attachments in addition to the basic loader bucket. Some of the many available attachments include:

- augers
- brooms
- buckets, general-purpose
- buckets, dirt
- buckets, utility
- buckets, light-material

Figure 4–10 Track loader. (Courtesy of John Deere Construction & Forestry Company)

buckets, multipurpose
cold planers
forks
hammers
landscape rake
rakes
stump grinders
tillers
trenchers
vibratory compactors

Material Handlers

Cranes and wheel loaders are often used to move materials around a construction site. However, specialized machines called *material handlers* or *rough-terrain forklifts* have been developed for this purpose. The material handler shown in Figure 4–14 has a maximum lift capacity of 9,000 lb (4082 kg) and a lift height of 40 ft (12 m). Other machines are available which have a maximum lift greater than 60 ft (18 m).

Figure 4–11 Backhoe loader. (Courtesy of JCB Inc.)

Figure 4–12 Skid-steer loader with backhoe attachment. (Courtesy of the Bobcat Company)

Figure 4–13 Compact track loader. (Courtesy of the Bobcat Company)

Estimating Loader Production

Loader production may be estimated as the product of average bucket load multiplied by cycles per hour (Equation 2–1). Basic cycle time for a loader includes the time required for loading, dumping, making four reversals of direction, and traveling a minimum distance (15 ft or less for track loaders). Table 4–6 presents typical values of basic cycle time for wheel and track loaders. While manufacturers' performance curves should be used whenever possible, typical travel-time curves for wheel loaders are presented in Figure 4–15.

Federal Highway Administration (FHWA) studies have shown little variation in basic cycle time for wheel loaders up to a distance of 80 ft (25 m) between loading and dumping position. Therefore, travel time should not be added until one-way distance exceeds this distance.

Loader bucket capacity is rated in heaped (loose) volume, as shown in Table 3–1. Bucket capacity should be adjusted by a bucket fill factor (Table 3–2) to obtain the best estimate of actual bucket volume.

Figure 4–14 Material handler. (Courtesy of JLG Industries, Inc.)

Table 4–6 Basic loader cycle time

	Basic Cycle Time (min)	
Loading Conditions	***Articulated Wheel Loader***	***Track Loader***
Loose materials	0.35	0.30
Average material	0.50	0.35
Hard materials	0.65	0.45

EXAMPLE 4–7

Estimate the hourly production in loose volume (LCY and LCM) of a 3½-yd (2.68-m^3) wheel loader excavating sand and gravel (average material) from a pit and moving it to a stockpile. The average haul distance is 200 ft (61 m), the effective grade is 6%, the bucket fill factor is 1.00, and job efficiency is 50 min/h.

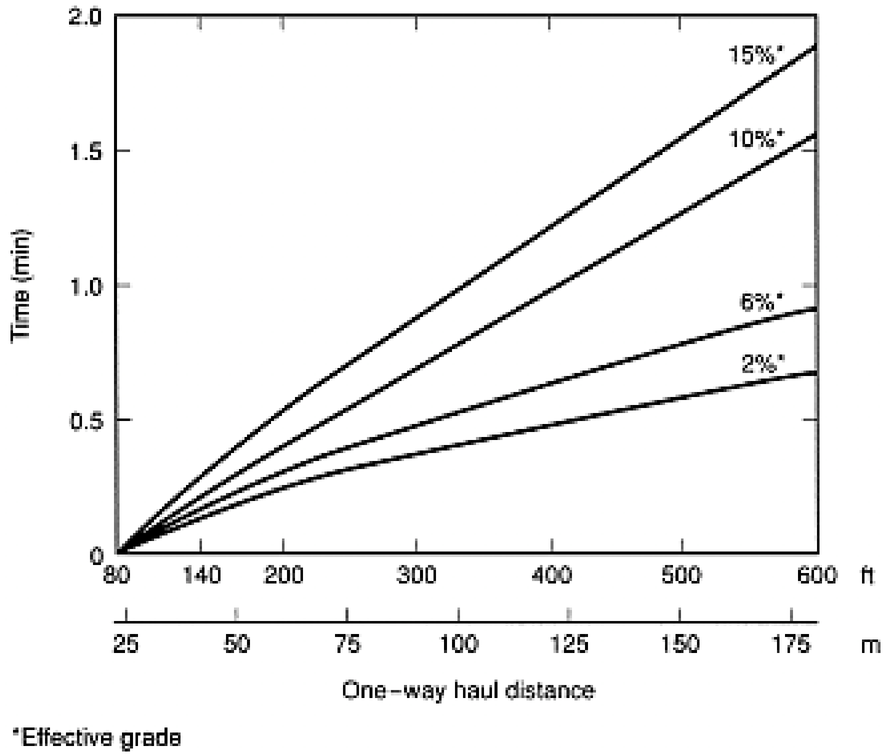

Figure 4–15 Travel time, wheel loader (haul + return).

SOLUTION

$$\text{Bucket volume} = 3.5 \times 1 = 3.5 \text{ LCY (2.68 LCM)}$$

$$\text{Basic cycle time} = 0.50 \text{ min} \quad \text{(Table 4–6)}$$

$$\text{Travel time} = 0.30 \text{ min} \quad \text{(Figure 4–14)}$$

$$\text{Cycle time} = 0.50 + 0.30 = 0.80 \text{ min}$$

$$\text{Production} = 3.5 \times \frac{50}{0.80} = 219 \text{ LCY/h}$$

$$\left[= 2.68 \times \frac{50}{0.80} = 168 \text{ LCM/h} \right]$$

Job Management

Some considerations involved in choosing a loader for a project have already been presented. Cutting of tires is a major problem when loading shot rock with a wheel loader. Type L-5 tires (rock, extra deep tread) should be used to increase tire life when loading rock. The

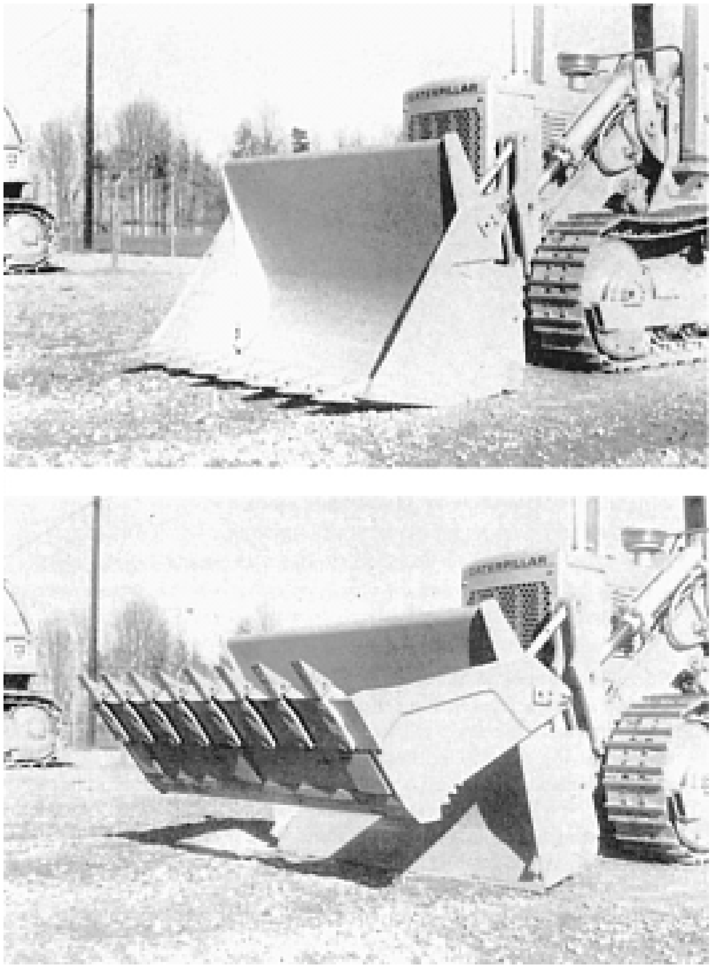

Figure 4–16 Multisegment loader bucket.

pit must be kept well drained, because water acts as a lubricant to increase the cutting action of rock on rubber tires.

Because of tipping load limitations, the weight of the material being handled may limit the size of the bucket that may be used on a loader. In selection of a loader, consideration must also be given to the clearances required during loading and dumping. Like excavators, optimum positioning of the loader and haul units will minimize loading, maneuver, and dump times. Multisegment buckets, also called 4-in-1 buckets and multipurpose buckets (Figure 4–16), are capable of performing as a clamshell, dozer, or scraper, as well as a conventional loader. Such buckets are often more effective than are conventional buckets in handling wet, sticky materials. Blasting or ripping hard materials before attempting to load them will often increase loader production in such materials.

Figure 4–17 Twin-engine all-wheel drive scraper. (Courtesy of Caterpillar Inc.)

4–4 SCRAPERS

Operation and Employment

Scrapers are capable of excavating, hauling, and dumping material over medium- to long-haul distances. However, only the elevating scraper and the pull-scraper are capable of achieving high efficiency in loading without the assistance of a pusher tractor or another scraper. Loading procedures are discussed later in this section. The scraper excavates (or cuts) by lowering the front edge of its bowl into the soil. The bowl front edge is equipped with replaceable cutting blades, which may be straight, curved, or extended at the center (stinger arrangement). Both the stinger arrangement and curved blades provide better penetration than does a straight blade. However, straight blades are preferred for finish work.

Although there are a number of different types of scrapers, principal types include single-engine overhung (two-axle) scrapers, three-axle scrapers, twin-engine all-wheel-drive scrapers, elevating scrapers, auger scrapers, push-pull or twin-hitch scrapers, and pull-scrapers. *Two-axle* or *overhung scrapers* utilize a tractor having only one axle (Figure 4–17). Such an arrangement has a lower rolling resistance and greater maneuverability than does a *three-axle scraper* that is pulled by a conventional four-wheel tractor. However, the additional stability of the three-axle scraper permits higher operating speeds on long, relatively flat haul roads. *All-wheel-drive scrapers,* as the name implies, utilize drive wheels on both the tractor and the scraper. Normally, such units are equipped with twin engines. The additional power and drive wheels give these units greater tractive effort than that of conventional scrapers. *Elevating scrapers* (Figure 4–18) utilize a ladder-type elevator to assist in cutting and lifting material into the scraper bowl. Elevating scrapers are not designed to be push-loaded and may be damaged by pushing. *Auger scrapers* are self-loading scrapers that use a rotating auger (similar to a posthole auger) located in the center of the scraper bowl to help lift material into the bowl. *Push-pull* or *twin-hitch scrapers* (Figure 4–19) are all-wheel-drive

Figure 4–18 Elevating scraper. (Courtesy of Caterpillar Inc.)

Figure 4–19 Twin-hitch scraper loading. (Courtesy of CMI Terex Corporation)

Figure 4–20 Pull scraper. (Courtesy of Deere & Company)

scrapers equipped with coupling devices that enable two scrapers to assist each other in loading. Their operation is described later in this section. *Pull-scrapers* (Figure 4–20) utilize one or more scraper pans towed by a tractor. One of the earliest types of scraper, these scrapers had largely fallen out of construction use but are now finding renewed construction application. When towed by a tractor having high-flotation tires, these units can operate under adverse soil conditions and are capable of loading without pusher assistance in sandy and sandy-clay soils. Such a combination has a lower initial price and lower operating cost than does a conventional scraper but can be even more productive on medium hauls in suitable soils. Pull-scrapers can also be connected in tandem as shown in Figure 4–21.

Estimating Scraper Production

Scraper cycle time is estimated as the sum of fixed cycle time and variable cycle time. Fixed cycle time in this case includes spot time, load time, and maneuver and dump time. Spot time represents the time required for a unit to position itself in the cut and begin loading, including any waiting for a pusher. Table 4–7 provides typical values of fixed cycle time for scrapers.

Variable cycle time, or travel time, includes haul time and return time. As usual, haul and return times are estimated by the use of travel-time curves or by using the average-speed method with performance and retarder curves. It is usually necessary to break a haul route up into sections having similar total resistance values. The total travel time required to traverse all sections is found as the sum of the section travel times.

In determining the payload per scraper cycle, it is necessary to check both the rated weight payload and the heaped volume capacity. The volume corresponding to the lesser of these two values will, of course, govern. The method of estimating production is illustrated in Examples 4–8 and 4–9.

Figure 4–21 Tandem Pull-Scrapers. (Courtesy of Deere & Company)

Table 4–7 Scraper fixed time (min)

	Spot Time	
Conditions	***Single Pusher***	***Tandem Pusher***
Favorable	0.2	0.1
Average	0.3	0.2
Unfavorable	0.5	0.5

	Load Time				
Conditions	***Single Pusher***	***Tandem Pusher***	***Elevating Scraper***	***Auger***	***Push-Pull****
Favorable	0.5	0.4	0.8	0.7	0.7
Average	0.6	0.5	1.0	0.9	1.0
Unfavorable	1.0	0.9	1.5	1.3	1.4

	Maneuver and Dump Time	
Conditions	***Single Engine***	***Twin Engine***
Favorable	0.3	0.3
Average	0.7	0.6
Unfavorable	1.0	0.9

*Per pair of scrapers.

EXAMPLE 4–8

Estimate the production of a single engine two-axle tractor scraper whose travel-time curves are shown in Figures 4–4 and 4–5 based on the following information.

Maximum heaped volume = 31 LCY (24 LCM)

Maximum payload = 75,000 lb (34020 kg)

Material: Sandy clay, 3200 lb/BCY (1898 kg/BCM),

2650 lb/LCY (1571 kg/LCM), rolling resistance 100 lb/ton (50 kg/t)

Job efficiency = 50 min/h

Operating conditions = average

Single pusher

Haul route:

Section 1. Level loading area

Section 2. Down a 4% grade, 2000 ft (610 m)

Section 3. Level dumping area

Section 4. Up a 4% grade, 2000 ft (610 m)

Section 5. Level turnaround, 600 ft (183 m)

SOLUTION

Load per cycle:

Weight of heaped capacity = 31 × 2650 = 82,150 lb

[= 24 × 1571 = 37 794 kg]

Weight exceeds rated payload of 75,000 lb (34,020 kg), therefore, maximum capacity is

$$\text{Load} = \frac{75{,}000}{3200} = 23.4 \text{ BCY/load}$$

$$\left[= \frac{34{,}020}{1898} = 17.9 \text{ BCM/load} \right]$$

Effective grade:

$$\text{Haul} = -4.0 + \frac{100}{20} = +1\%$$

$$\left[= -4.0 + \frac{50}{10} = +1\% \right]$$

$$\text{Return} = 4.0 + \frac{100}{20} = +9\%$$

$$\left[= 4.0 + \frac{50}{10} = +9\% \right]$$

$$\text{Turnaround} = 0 + \frac{100}{20} = 5\%$$

$$\left[= 0 + \frac{50}{10} = +5\%\right]$$

Travel time:

$$\begin{aligned} \text{Section 2} &= 1.02 \text{ min} && \text{(Figure 4–4)} \\ \text{Section 4} &= 1.60 \text{ min} && \text{(Figure 4–5)} \\ \text{Section 5} &= \underline{0.45 \text{ min}} && \text{(Figure 4–5)} \\ \text{Total} &= 3.07 \text{ min} \end{aligned}$$

Fixed cycle (Table 4–7):

$$\begin{aligned} \text{Load spot} &= 0.3 \text{ min} \\ \text{Load} &= 0.6 \text{ min} \\ \text{Maneuver and dump} &= \underline{0.7 \text{ min}} \\ \text{Total} &= 1.6 \text{ min} \\ \text{Total cycle time} &= 3.07 + 1.6 \text{ min} = 4.67 \text{ min} \end{aligned}$$

$$\text{Estimated production} = 23.4 \times \frac{50}{4.67} = 251 \text{ BCY/h}$$

$$\left[= 17.9 \times \frac{50}{4.67} = 192 \text{ BCM/h}\right]$$

EXAMPLE 4–9

Solve the problem of Example 4–8 using the average-speed method and the performance curves of Figure 4–2.

SOLUTION

Payload = 23.4 BCY (17.9 BCM) from Example 4–8

Effective grades from Example 4–8:

$$\begin{aligned} \text{Haul} &= +1.0\% \\ \text{Return} &= +9.0\% \\ \text{Turnaround} &= +5.0\% \end{aligned}$$

Maximum speed (Figure 4–2):

$$\begin{aligned} \text{Haul} &= 32 \text{ mi/h (52 km/h)} \\ \text{Return} &= 16 \text{ mi/h (26 km/h)} \\ \text{Turnaround} &= 28 \text{ mi/h (45 km/h)} \end{aligned}$$

Average speed factor (Table 4–3):

$$\text{Haul} = 0.86 \times 0.86 = 0.74$$
$$\text{Return} = 0.86$$
$$\text{Turnaround} = 0.68$$

Average speed:

$$\text{Haul} = 32 \times 0.74 = 24 \text{ mi/h (38 km/h)}$$
$$\text{Return} = 16 \times 0.86 = 13 \text{ mi/h (22 km/h)}$$
$$\text{Turnaround} = 28 \times 0.68 = 19 \text{ mi/h (31 km/h)}$$

Travel time:

$$\text{Haul} = \frac{2000}{24 \times 88} = 0.95 \text{ min}$$
$$\left[= \frac{610}{38 \times 16.7} = 0.95 \text{ min}\right]$$
$$\text{Return} = \frac{2000}{13 \times 88} = 1.75 \text{ min}$$
$$\left[= \frac{610}{21 \times 16.7} = 1.75 \text{ min}\right]$$
$$\text{Turnaround} = \frac{600}{19 \times 88} = 0.36 \text{ min}$$
$$\left[= \frac{183}{31 \times 16.7} = 0.36 \text{ min}\right]$$
$$\text{Total} = 3.06 \text{ min}$$
$$\text{Fixed cycle} = 1.6 \text{ min}$$
$$\text{Total cycle time} = 4.66 \text{ min}$$
$$\text{Estimated production} = 23.4 \times \frac{50}{4.66} = 251 \text{ BCY/h}$$
$$\left[= 17.9 \times \frac{50}{4.66} = 192 \text{ BCM/h}\right]$$

(Example 4–8)

Note: The travel-time curves of Figures 4–4 and 4–5 assume acceleration from an initial velocity of 2.5 mi/h (4 km/h) upon leaving the cut and fill and deceleration to 2.5 mi/h (4 km/h) upon entering the cut and fill. The result of adding together the travel times for several sections will, because of an excessive allowance for acceleration and deceleration, yield a travel time greater than that obtained by the use of the average-speed method. The time estimate obtained by the use of the average-speed method should be more realistic.

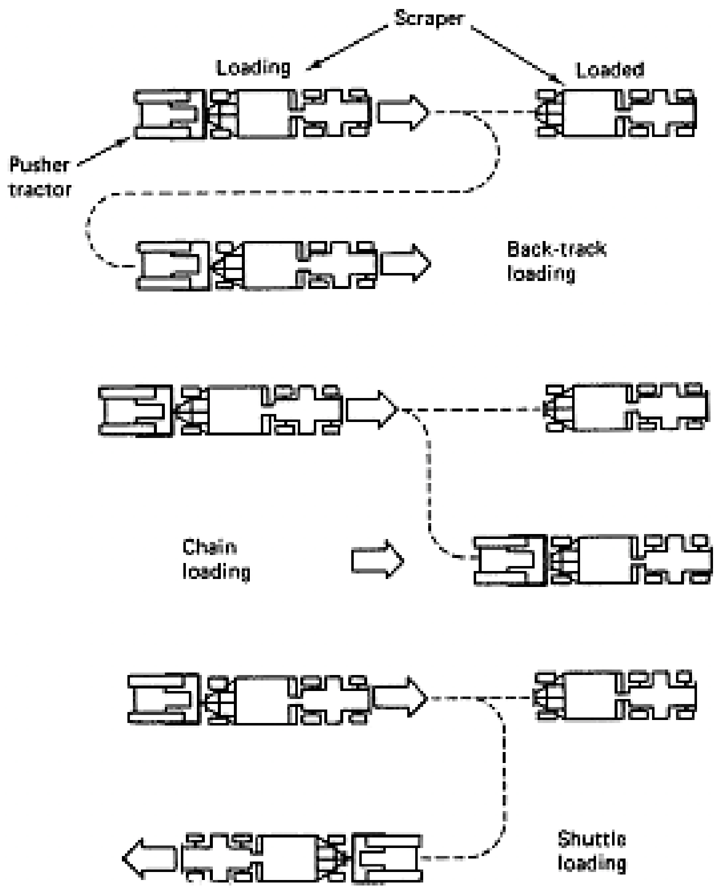

Figure 4–22 Methods of push-loading scrapers.

Push-Loading

Except for elevating, pull-scrapers, and push-pull scrapers, wheel scrapers require the assistance of pusher tractors to obtain maximum production. The three basic methods of push-loading scrapers are illustrated in Figure 4–22. The back-track method is most commonly used since it permits all scrapers to load in the same general area. However, it is also the slowest of the three methods because of the additional pusher travel distance. Chain loading is suitable for a long, narrow cut area. Shuttle loading requires two separate fill areas for efficient operations.

A complete pusher cycle consists of maneuver time (while the pusher moves into position and engages the scraper), load time, boost time (during which the pusher assists in accelerating the scraper out of the cut), and return time. Tandem pushing involves the use

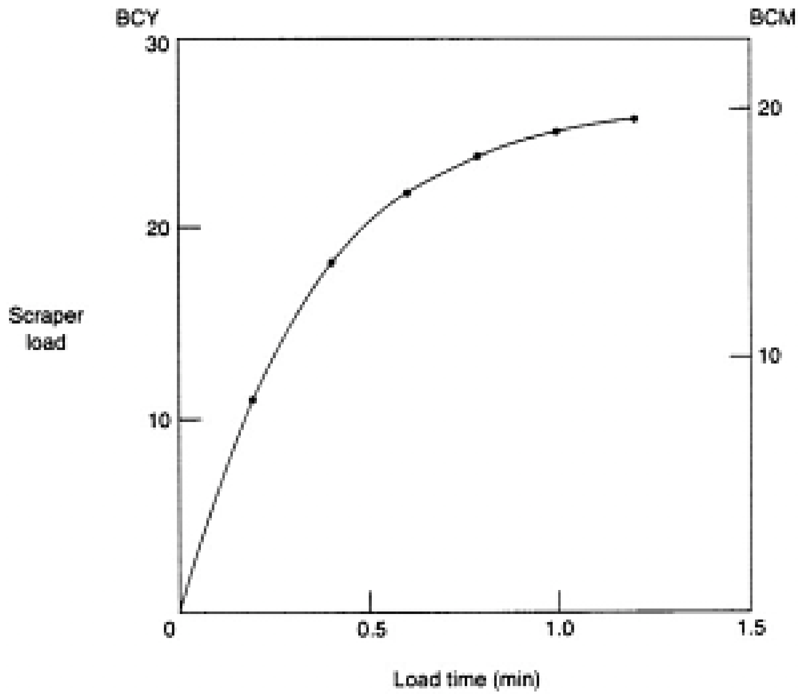

Figure 4–23 A load growth curve.

of two pusher tractors operating one behind the other during loading and boosting. The use of tandem pushers reduces scraper load time and frequently results in obtaining larger scraper loads. The dual tractor described in Section 4–2 is a more efficient pusher than tandem tractors because the dual tractor is controlled by a single operator and no time is lost in coordination between two operators.

Optimum Load Time

In field studies performed by Caterpillar Inc., it was found that the scraper loading time which yielded maximum scraper production in a given situation was usually less than the loading time required to obtain the maximum scraper load. Caterpillar called the loading time which yielded maximum production the *optimum load time.* A simple method for determining the optimum load time is described below.

To determine the optimum load time it is first necessary to plot the volume of scraper load versus loading time. To do this, the scraper must be loaded for controlled periods of time and weighed each time after loading. The load weight is then converted into scraper volume and plotted as a *load growth curve* (see Figure 4–23). As you recognize, the slope of the load growth curve at any loading time corresponds to the rate of loading at that time.

A simple graphical method for determining the optimum load time is illustrated in Figure 4–24. First, extend the horizontal axis of the load growth curve to the left of the origin. Next, locate a point (A) on this axis whose distance from the origin represents "total

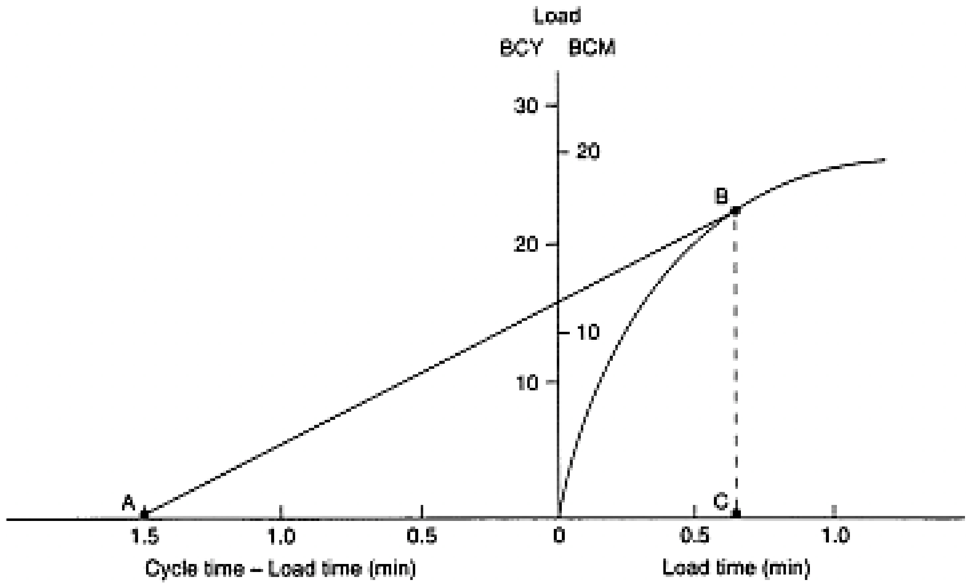

Figure 4–24 Finding the optimum load time.

Table 4–8 Typical pusher cycle time (min)

Loading Method	Single Pusher	Tandem Pusher
Back-track	1.5	1.4
Chain or shuttle	1.0	0.9

cycle time less loading time." Finally, draw a tangent to the load growth curve from Point A intersecting the curve at Point B. The loading time (C) corresponding to Point B is the optimum load time. To prove this, realize that the distance A–C represents total scraper cycle time and B–C represents the corresponding volume per cycle. The slope of the line A–B thus represents production (volume) per unit of time. When the slope of A–B is at a maximum, the scraper production per unit of time is maximized.

Calculating the Number of Pushers Required

The number of scrapers that can theoretically be handled by one pusher without a scraper having to wait for a pusher can be calculated by the use of Equation 4–11. The number of pushers required to fully service a given scraper fleet may then be determined from Equation 4–12. It is suggested that the result obtained from Equation 4–11 be rounded down to one decimal place for use in Equation 4–12. The result obtained from Equation 4–12 must be rounded up to the next whole number to ensure that scrapers do not have to wait for a pusher. Methods for estimating scraper cycle time have already been presented. Table 4–8 may be used for estimating pusher cycle time.

$$\text{Number of scrapers served} = \frac{\text{Scraper cycle time}}{\text{Pusher cycle time}} \qquad \textbf{(4–11)}$$

$$\text{Number of pushers required} = \frac{\text{Number of scrapers}}{\text{Number served by one pusher}} \qquad \textbf{(4–12)}$$

When the number of pushers actually used is less than the number required to fully serve the scraper fleet, expected production is reduced to that obtained using Equation 4–13. In performing this calculation, use the precise number of pushers required, not the integer value.

$$\text{Production} = \frac{\text{No. of pushers}}{\text{Required number}} \times \text{No. of scrapers} \times \text{Production per scraper} \qquad \textbf{(4–13)}$$

EXAMPLE 4–10

The estimated cycle time for a wheel scraper is 6.5 min. Calculate the number of pushers required to serve a fleet of nine scrapers using single pushers. Determine the result for both back-track and chain loading methods.

SOLUTION

Number of scrapers per pusher (Eq 4–11):

$$\text{Back-track} = \frac{6.5}{1.5} = 4.3$$

$$\text{Chain} = \frac{6.5}{1.0} = 6.5$$

Number of pushers required (Eq 4–12):

$$\text{Back-track} = \frac{9}{4.3} = 2.1 = 3$$

$$\text{Chain} = \frac{9}{6.5} = 1.4 = 2$$

EXAMPLE 4–11

Find the expected production of the scraper fleet of Example 4–10 if only one pusher is available and the chain loading method is used. Expected production of a single scraper assuming adequate pusher support is 226 BCY/h (173 BCM/h).

SOLUTION

Number of pushers required to fully serve fleet = 1.4

$$\text{Production} = \frac{1}{1.4} \times 9 \times 226 = 1453 \text{ BCY/h} \qquad \text{(Eq 4–13)}$$

$$\left[= \frac{1}{1.4} \times 9 \times 173 = 1112 \text{ BCM/h} \right] \qquad \text{(Eq 4–13)}$$

Push-Pull Loading

In *push-pull* or *twin-hitch* scraper loading, two all-wheel-drive scrapers assist each other to load without the use of pusher tractors. The scrapers are equipped with special push blocks and coupling devices, as shown in Figure 4–19. The sequence of loading operations is as follows:

1. The first scraper to arrive in the cut starts to self-load.
2. The second scraper arrives, makes contact, couples, and pushes the front scraper to assist it in loading.
3. When the front scraper is loaded, the operator raises its bowl. The second scraper then begins to load with the front scraper pulling to assist in loading.
4. The two scrapers uncouple and separate for the haul to the fill.

Although there are a number of advantages claimed for this method of loading, basically it offers the loading advantages of self-loading scrapers while retaining the hauling advantages of standard scrapers. No pusher tractor or its operator is required. There is no problem of pusher-scraper mismatch and no lost time due to pusher downtime. However, scrapers must operate in pairs so that if one scraper breaks down, its partner must be diverted to a different operation. Conditions favoring push-pull operations include long, straight hauls with relatively easy to load materials. An adequate number of spreading and compacting units must be available at the fill, since two scrapers dump almost simultaneously.

Job Management

The type of scraper that may be expected to yield the lowest cost per unit of production is a function of the total resistance and the haul distance, as shown in Figure 4–25. Elevating scrapers can use their self-loading ability effectively for short hauls. However, their additional weight puts them at a disadvantage on long hauls. Of the conventional scrapers, single-engine overhung units are best suited to medium distances on relatively flat haul roads where maneuverability is important and adequate pusher power is available. Three-axle units are faster on long hauls and uneven surfaces. All-wheel-drive tandem-powered units are favored for conditions of high total resistance at all but the shortest haul distances. Notice that push-pull or twin-hitch scrapers overlap the entire all-wheel-drive zone of Figure 4–25 and extend into the elevating and conventional zones.

Some techniques for maximizing scraper production include:

- Use downhill loading whenever possible to reduce the required pusher power and load time.
- Use chain or shuttle loading methods if possible.
- Use rippers or scarifiers to loosen hard soils before attempting to load.
- Have pushers give scrapers an adequate boost to accelerate units out of the cut.
- Keep the cut in good condition by using pushers during their idle time or by employing other equipment. Provide adequate drainage in the cut to improve trafficability.
- Maintain the haul road in the best possible condition. Full-time use of a motor grader on the haul road will usually pay off in increased scraper production.
- Make the haul road wide enough to permit high-speed hauling without danger. One-way haul roads should be utilized whenever possible.

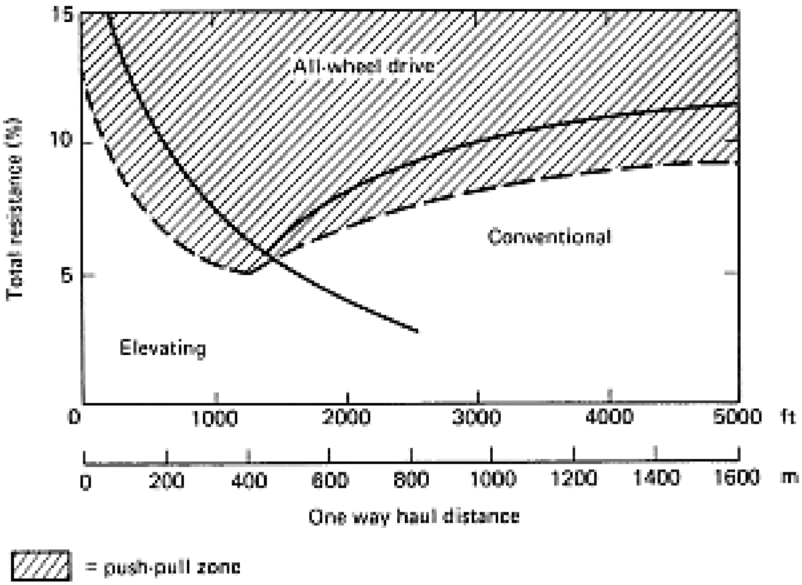

Figure 4–25 Scraper application zones.

- Keep the fill surface smooth and compacted to minimize scraper time in the fill.
- Boost scrapers on the fill if spreading time is excessive.

Supervisors must carefully control operations in the cut, on the haul road, and in the fill to maximize production. Scrapers must be kept evenly spaced throughout their cycle to avoid interference between units. Scrapers that break down or cannot maintain their place in the cycle must be repaired promptly or replaced by standby units.

4–5 TRUCKS AND WAGONS

Operation and Employment

Because hauling (or the transportation of excavation) is a major earthmoving activity, there are many different types of hauling equipment available to the constructor. In addition to the dozer, loader, and scraper already described, hauling equipment includes trucks, wagons, conveyor belts, and trains. Most of the belt-type conveyors used in construction are portable units used for the movement of bulk construction materials within a small area or for placing concrete. However, conveyors are capable of moving earth and stone relatively long distances at high speed. Their ability to move earth for highway construction has been demonstrated in Great Britain. In the United States, they have been utilized on a number of large construction projects, such as dams. Their application is primarily limited by their large capital cost.

Conventional freight trains may be used to haul earth or rock over long distances when tracks are located near the excavation and fill areas. However, most construction applications involve narrow-gauge rail lines built in the construction area. This type of equipment is often used to remove the spoil from tunneling. Special rail cars are available for hauling plastic concrete. Although not usually thought of as a piece of earthmoving equipment, a dredge is capable of excavating soil and fractured rock and transporting it through pipelines in the form of a slurry.

Trucks and wagons are still the most common forms of construction hauling equipment. The heavy-duty rear-dump truck is most widely used because of its flexibility of use and the ability of highway models to move rapidly between job sites. There are a wide variety of types and sizes of dump truck available. Trucks may be powered by diesel or gasoline engines, have rear axle or all-wheel drive, have two or three axles, be equipped with standard or rock bodies, and so on. Trucks used for hauling on public highways are limited by transportation regulations in their maximum width, gross weight, and axle load. There is a growing trend toward the use of off-highway models that can be larger and heavier and carry payloads up to several hundred tons. Figure 4–26 shows a 41-ton rear-dump truck being loaded by a shovel. The all-wheel-drive articulated dump truck illustrated in Figure 4–27 (also called an *articulated hauler*) is finding increasing usage because of its ability to carry large loads over low-trafficability soils.

Figure 4–26 41-ton rear-dump truck. (Courtesy of Volvo Construction Equipment North America, Inc.)

Figure 4–27 All-wheel-drive articulated dump truck. (Courtesy of CMI Terex Corporation)

Wagons are earthmoving trailers pulled by tractors or truck-tractors. They are sometimes referred to as pure haulers because they have many characteristics of tractor-scrapers, but they are designed for hauling only. They are available in bottom-dump, end-dump, and side-dump models. Bottom-dump models are often preferred for moving earth and crushed rock because of their ability to dump and spread while moving at a relatively high speed. Dump gates are available as either longitudinal flow gates or cross-flow gates. Longitudinal flow dumping is desirable for windrowing and stockpiling while cross-flow dumping permits better spreading of base materials and aggregates. Some wagons are capable of either cross-flow or longitudinal-flow spreading. Although wagons are independent pieces of equipment, some are especially designed to work with a particular make and model of tractor. A 70-ton, bottom-dump wagon equipped with two longitudinal-flow gates is shown in Figure 4–28.

Determining the Number of Haul Units Needed

The components of the truck or wagon cycle are similar to those of the scraper described in Section 4–4. Thus total cycle time is the sum of the fixed time (spot, load, maneuver, and dump) and the variable time (haul and return). The fixed time elements of spot, maneuver, and dump may be estimated by the use of Table 4–9. Loading time, however, should be calculated by the use of Equation 4–14 or 4–15.

$$\text{Load time} = \frac{\text{Haul unit capacity}}{\text{Loader production at 100\% efficiency}} \qquad \textbf{(4–14)}$$

$$\text{Load time} = \text{Number of bucket loads} \times \text{Excavator cycle time} \qquad \textbf{(4–15)}$$

Figure 4–28 Bottom-dump wagon. (Courtesy of CMI Terex Corporation)

Table 4–9 Spot, maneuver, and dump time for trucks and wagons (min)

Conditions	Bottom Dump	Rear Dump
Favorable	1.1	0.5
Average	1.6	1.1
Unfavorable	2.0	2.5

The reason for using an excavator loading rate based on 100% excavator efficiency in Equation 4–14 is that excavators have been found to operate at or near-100% efficiency when actually loading. Thus the use of the 100% efficiency loading rate is intended to ensure that an adequate number of trucks is provided so that the excavator will not have to wait for a truck. Either bank or loose measure may be used in Equation 4–14, but the same unit must be used in both numerator and denominator.

The number of trucks theoretically required to keep a loader fully occupied and thus obtain the full production of the loader may be calculated by the use of Equation 4–16. Although this method gives reasonable values for field use, it should be recognized that some instances of the loader waiting for haul units will occur in the field when this method is used. This is due to the fact that some variance in loader and hauler cycle time will occur in the real-world situation. More realistic results may be obtained by the use of computer simulation techniques or the mathematical technique known as queueing theory (see reference 5).

$$\text{Number of haulers required } (N) = \frac{\text{Haul unit cycle time}}{\text{Load time}} \quad \textbf{(4–16)}$$

The result obtained from Equation 4–16 must be rounded up to the next integer. Using this method, the expected production of the loader/hauler system is the same as though the excavator were simply excavating and stockpiling. Reviewing the procedure, system output is assumed to equal normal loader output, including the usual job efficiency factor. However, the number of haul units required is calculated using 100% loader efficiency.

If more than the theoretically required number of trucks is supplied, no increase in system production will occur, because system output is limited to excavator output. However, if less than the required number of trucks is supplied, system output will be reduced, because the excavator will at times have to wait for a haul unit. The expected production in this situation may be calculated by the use of Equation 4–17. In performing this calculation, use the precise value of N, not its integer value.

$$\begin{matrix}\text{Expected production} \\ \text{(no. units less than } N\text{)}\end{matrix} = \frac{\text{Actual Number of units}}{N} \times \begin{matrix}\text{Excavator} \\ \text{production}\end{matrix} \quad \textbf{(4–17)}$$

EXAMPLE 4–12

Given the following information on a shovel/truck operation, (a) calculate the number of trucks theoretically required and the production of this combination; (b) calculate the expected production if two trucks are removed from the fleet.

Shovel production at 100% efficiency = 371 BCY/h (283 BCM/h)
Job efficiency = 0.75
Truck capacity = 20 BCY (15.3 BCM)
Truck cycle time, excluding loading = 0.5 h

SOLUTION

(a)

$$\text{Load time} = \frac{20}{371} = 0.054\text{ h} \qquad \text{(Eq 4–14)}$$

$$\left[= \frac{15.3}{283} = 0.054\text{ h}\right]$$

$$\text{Truck cycle time} = 0.5 + 0.054 = 0.554 \text{ h}$$

$$\text{Number of trucks required} = \frac{0.554}{0.054} = 10.3 = 11 \qquad \text{(Eq 4–16)}$$

$$\text{Expected production} = 371 \times 0.75 = 278 \text{ BCY/h}$$

$$[= 283 \times 0.75 = 212 \text{ BCM/h}]$$

(b) With nine trucks available,

$$\text{Expected production} = \frac{9}{10.3} \times 278 = 243 \text{ BCY/h} \qquad \text{(Eq 4–17)}$$

$$\left[= \frac{9}{10.3} \times 212 = 186 \text{ BCM/h}\right]$$

Job Management

An important consideration in the selection of excavator/haul unit combinations is the effect of the size of the target that the haul unit presents to the excavator operator. If the target is too small, excessive spillage will result and excavator cycle time will be increased. Studies have found that the resulting loss of production may range from 10 to 20%. As a rule, haul units loaded by shovels, backhoes, and loaders should have a capacity of 3 to 5 times excavator bucket capacity. Because of their less precise control, clamshells and draglines require larger targets. A haul unit capacity of 5 to 10 times excavator bucket capacity is recommended for these excavators. Haul units that hold an integer number of bucket loads are also desirable. Using a partially filled bucket to top off a load is an inefficient operation.

Time lost in spotting haul units for loading is another major cause of inefficiency. As discussed under excavator operations, reducing the excavator swing angle between digging and loading will increase production. The use of two loading positions, one on each side of the excavator, will reduce the loss of excavator production during spotting. When haul units are required to back into loading position, bumpers or spotting logs will assist the haul unit operator in positioning his vehicle in the minimum amount of time.

Some other techniques for maximizing haul unit production include:

- If possible, stagger starting and quitting times so that haul units do not bunch up at the beginning and end of the shift.
- Do not overload haul units. Overload results in excessive repair and maintenance.
- Maintain haul roads in good condition to reduce travel time and minimize equipment wear.
- Develop an efficient traffic pattern for loading, hauling, and dumping.
- Roads must be wide enough to permit safe travel at maximum speeds.
- Provide standby units (about 20% of fleet size) to replace units that break down or fail to perform adequately.
- Do not permit speeding. It is a dangerous practice; it also results in excessive equipment wear and upsets the uniform spacing of units in the haul cycle.

In unit price earthmoving contracts, payment for movement of soil or rock from cut to fill that exceeds a specified distance is termed *overhaul.* Overhaul can be minimized by selection of an optimum design surface elevation (grade) and by use of borrow and waste areas at appropriate locations.

PROBLEMS

1. The load growth data for a scraper are given here. The scraper's total cycle time minus load time is 3.5 min. Find the scraper's optimum load time.

	Average Load	
Load Time (min)	**BCY**	**BCM**
0.2	10.8	8.3
0.4	17.8	13.6
0.6	21.6	16.5
0.8	23.6	18.0
1.0	24.8	19.0
1.2	25.5	19.5
1.4	25.8	19.8

2. A power-shift crawler tractor is excavating tough clay and pushing it a distance of 95 ft (29 m). Maximum reverse speeds are: first range, 3 mi/h (4.8 km/h); second range, 5 mi/h (8.1 km/h); and third range, 8 mi/h (12.9 km/h). Rated blade capacity is 10 LCY (7.65 LCM). Estimate dozer production if the job efficiency factor is 0.83.
3. Using the data of Problem 7, calculate the expected production and unit cost of loading and hauling if the truck fleet consists of five trucks.
4. The scraper whose performance curve is shown in Figure 4–2 is operating at an altitude at which the derating factor is 10%. The scraper is operating up a grade of 3% over a haul road having a rolling resistance factor of 100 lb/ton (50 kg/t). What is the maximum speed of the scraper when carrying its rated load?
5. How many hours should it take an articulated wheel loader equipped with a 4-yd (3.06-m^3) bucket to load 3,000 cu yd (2294 m^3) of gravel from a stockpile into rail cars if the average haul distance is 300 ft (91.5 m) one way? The area is level with a rolling resistance factor of 120 lb/ton (60 kg/t). Job efficiency is estimated at 50 min/h.
6. The tractor-scraper whose travel-time curves are shown in Figures 4–4 and 4–5 hauls its rated payload 4000 ft (1220 m) up a 5% grade from the cut to the fill and returns empty over the same route. The rolling resistance factor for the haul road is 120 lb/ton (60 kg/t). Estimate the scraper travel time.
7. A hydraulic shovel will be used to excavate sandy clay and load it into 12-BCY (9.2-BCM) dump trucks. The shovel's production at 100% efficiency is estimated to be 300 BCY/h (229 BCM/h), and job efficiency is 0.80. Truck travel time is estimated to be 8.0 min, and truck fixed-cycle time (excluding loading) is estimated to be 2.0 min. Equipment costs for the shovel and trucks are $40/h and $20/h, respectively.

a. How many trucks are theoretically required to obtain maximum production?
b. What is the expected production of the system in bank measure using this number of trucks?
c. What is the expected unit loading and hauling cost ($/BCY or $/BCM)?

8. A wheel tractor-scraper whose weight on the driving wheels is 38,720 lb (17,563 kg) has a gross weight of 70,400 lb (31,933 kg). If the road surface is dry earth with a rolling resistance factor of 100 lb/ton (50 kg/t), what is the maximum grade the scraper could ascend?
9. What is a pull-scraper? What advantages does it have over conventional scrapers?
10. Write a computer program to calculate the number of pushers required to service a specified scraper fleet. Input should include scraper cycle time, method of push-loading, and whether single or tandem pushers will be used. Using your program, verify the solution given in Example 4–10.

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