# Chapter 4

## Loading and Hauling

### *Part 3*

# 4-4 SCRAPERS

- Operation and Employment
- Estimating Scraper Production
- Push-Loading
- Optimum Load Time
- Calculating the Number of Pushers Required
- Push-Pull Loading
- Job Management


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# Operation and Employment

- Scrapers are capable of:
  - excavating
  - loading
  - hauling
  - dumping material over medium to long haul distances
- The scraper excavates (or cuts) by lowering the front edge of it’s bowl into the soil

# Operation and Employment

- Principal scrapers types include:
  - 1. Single-engine overhung (two-axle) scrapers
  - 2. Three-axle scrapers
  - 3. Twin-engine all-wheel-drive scrapers
  - 4. Elevating scrapers
  - 5. Auger scrapers
  - 6. Push-pull or twin-hitch scrapers
  - 7. Pull-scrapers
- Only the elevating scraper is capable of achieving high efficiency in loading without the assistance of a pusher tractor or another scraper

# 2. Three-axle scrapers

https://www.youtube.com/watch?v=UYZYPIWBl84

# Operation and Employment

- ***Two-axle or overhung scrapers Vs Three-axle scrapers***
  - utilize a tractor having only one axle.
  - 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.

# 3. Twin-engine all-wheel drive scraper.

# Operation and Employment

- ***Twin engine -All-wheel-drive scrapers***,
  - as the name implies, utilize drive wheels on both the tractor and 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.

# 4. Elevating scrapers

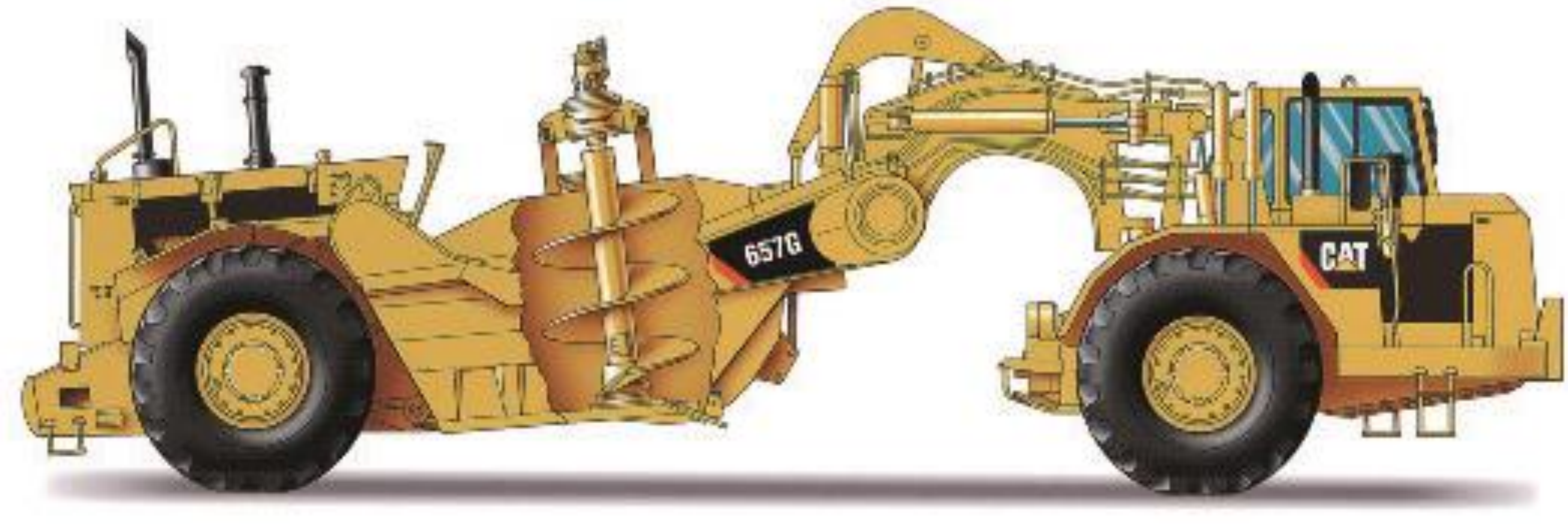
Miniature Elevating scrapers

***Elevating scrapers***

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.

# 5. Auger scrapers




*Auger scrapers* are self-loading scrapers that use a rotating auger (similar to a pothole auger) located in the center of the scraper bowl to help lift material into the bowl.

# *6. Push-pull* or *twin-hitch scrapers*

*Push-pull* or *twin-hitch scrapers* : are all-wheel-drive scrapers equipped with coupling devices that enable two scrapers to assist each other in loading.

# 7. Pull scraper.
# (Courtesy of Deere & Company)

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

https://www.youtube.com/watch?v=TRnSUUZs4Xs

SCRAPER
http://www.youtube.com/watch?v=BzAjyMEeDYg

PUSH-LOADING
http://www.youtube.com/watch?v=f5xq8jOObJY

WHEEL SCRAPER
http://www.youtube.com/watch?v=sk2OGTvamu4

# Estimating Scraper Production

- Scraper cycle time is estimated as the sum of:
  - fixed cycle time
  - variable cycle time
- Fixed cycle time (Table 4-7) in this case includes:
  - spot time
  - load time
  - 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** 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 |

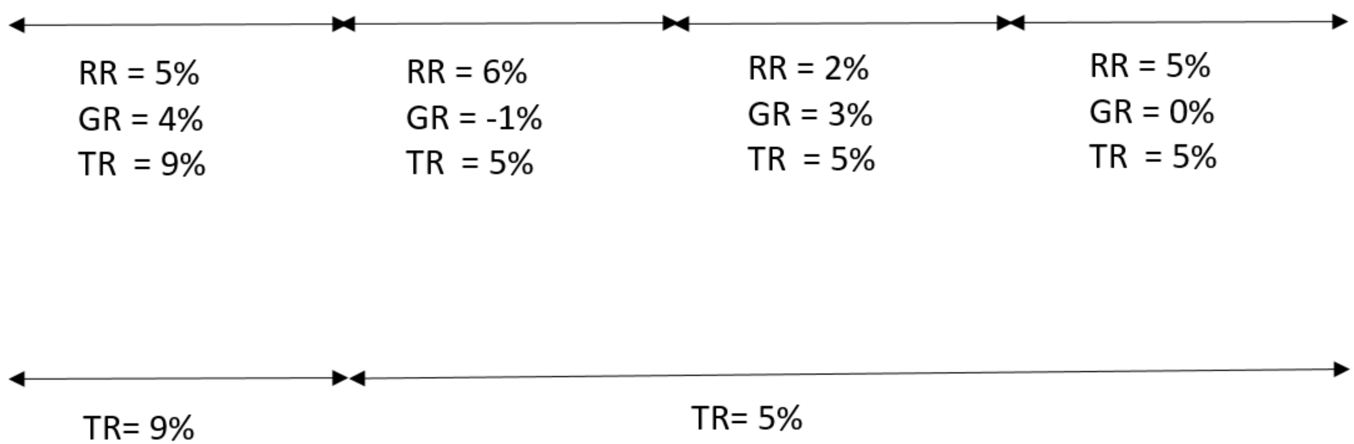
| | Maneuver and Dump Time | |
|---|---|---|
| **Conditions** | ***Single Engine*** | ***Twin Engine*** |
| Favorable | 0.3 | 0.3 |
| Average | 0.7 | 0.6 |
| Unfavorable | 1.0 | 0.9 |

*Per pair of scrapers.

# Estimating Scraper Production

- Variable cycle time, or travel time, includes:
  - haul time
  - return time
- 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 (i.e. combining adjacent sections that have similar total resistance (effective grade)).
- The total travel time required to traverse all sections is found as the sum of the section travel times.

Haul or Return route



**Haul**

| | | | |
|---|---|---|---|
| RR= 4%<br>GR=2%<br>TR= 6%<br>Case= 1 | RR= 6%<br>GR=4%<br>TR=10%<br>Case= 3 | RR= 5%<br>GR=3%<br>TR= 8%<br>Case= 2 | RR= 4%<br>GR=2%<br>TR= 6%<br>Case= 1 |

**Return**

| | | | |
|---|---|---|---|
| RR= 4%<br>GR= - 2%<br>TR= 2%<br>Case= | RR= 6%<br>GR= - 4%<br>TR=2 %<br>Case= | RR= 5%<br>GR= - 3%<br>TR= 2%<br>Case= | RR= 4%<br>GR= - 2%<br>TR= 2%<br>Case= |

**(Case 1)** 2

**Table 4–3** Average speed factors

| Length of Haul Section ft | m | Case 1 Starting from 0 or Coming to a Stop | Case 2 Increasing Maximum Speed from Previous Section | Case 3 Decreasing Maximum Speed from Previous Section |
|---|---|---|---|---|
| 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 |

# Estimating Scraper Production

Volume per cycle

- In determining the payload per scraper cycle, it is necessary to check both:
  - 1. the rated weight payload
  - 2. the heaped volume capacity
- The volume corresponding to the lesser of these two values will, of course, govern.

# 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 = 24 LCM
  - Maximum payload = 34020 kg
  - Material: Sandy clay, 1898 kg/BCM, 1571 kg/LCM, rolling resistance factor 50 kg/t.
  - Job efficiency =50 min/h
  - Operating conditions =average
  - Single pusher

# EXAMPLE 4-8

Haul route:

Section 1. Level loading area

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

Section 3. Level dumping area

Return route:

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

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

# EXAMPLE 4-8

## Solution

Load per cycle (volume per cycle):

Weight of heaped capacity =24 × 1571 =37794 kg

Weight exceeds rated payload of 34020 kg, therefore, maximum capacity is

Load = 34020 / 1898 = 17.9 BCM/load

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)

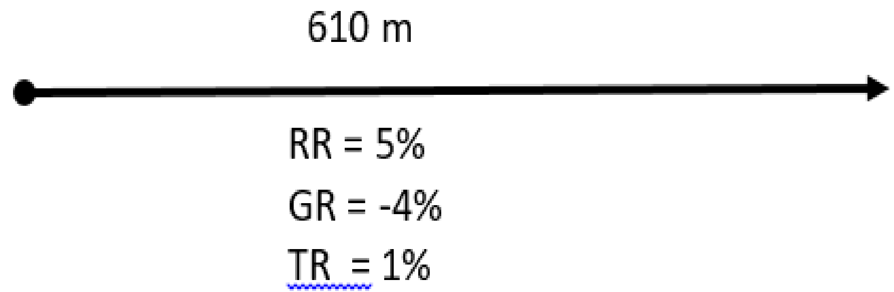
Effective grade:

Section 2- Haul = -4.0 + 50/10 = +1%

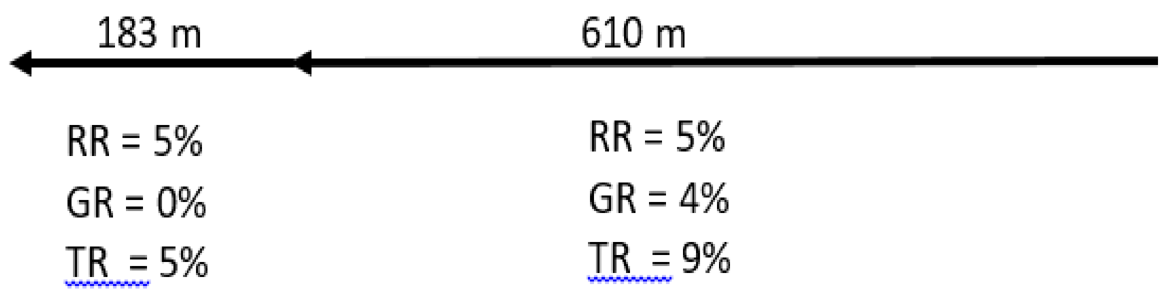
Section 4 - Return = 4.0 + 50/10 = +9%

Section 5 - Turnaround = 0 + 50/10 = +5%

Haul route




Return route



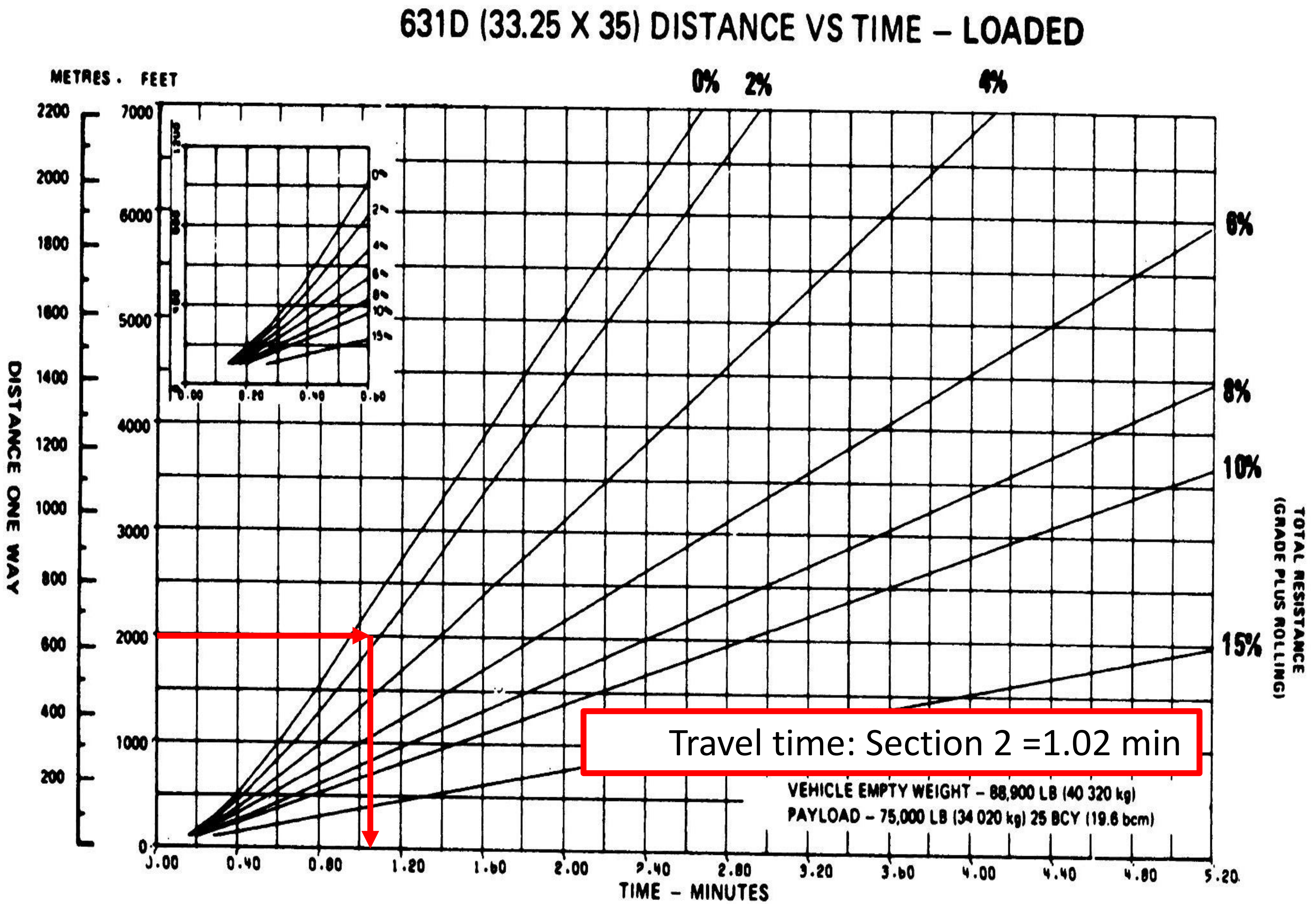



**Figure 4–4** Scraper travel time—loaded. (Courtesy of Caterpillar Inc.)

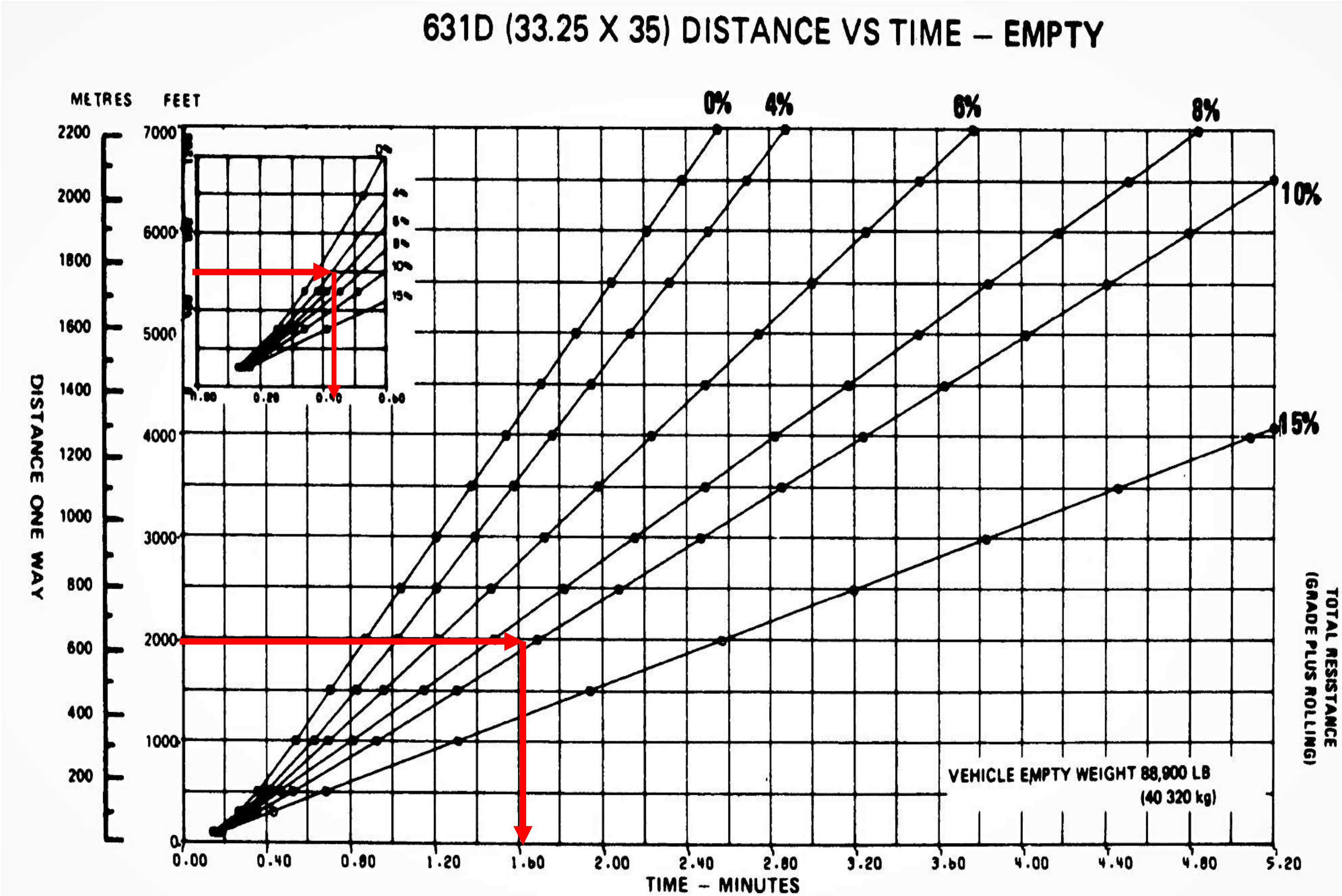



**Figure 4–5** Scraper travel time—empty.

Travel time: Section 4 =1.60 min

# Variable Time

Travel time:

| | |
|---|---|
| Section 2 =1.02 min | (Figure 4-4) |
| Section 4 =1.60 min | (Figure 4-5) |
| Section 5 =0.45 min | (Figure 4-5) |
| Total =3.07 min | |

**Table 4-7** Scraper fixed time (min)

| Conditions | Spot Time: Single Pusher | Spot Time: Tandem Pusher |
|---|---|---|
| Favorable | 0.2 | 0.1 |
| Average | 0.3 | 0.2 |
| Unfavorable | 0.5 | 0.5 |

| Conditions | Load Time: Single Pusher | Tandem Pusher | Elevating Scraper | Auger |
|---|---|---|---|---|
| Favorable | 0.5 | 0.4 | 0.8 | 0.7 |
| Average | 0.6 | 0.5 | 1.0 | 0.9 |
| Unfavorable | 1.0 | 0.9 | 1.5 | 1.3 |

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

Fixed cycle

Spot =0.3 min

Load =0.6 min

Maneuver and dump =0.7 min

Total = 1.6 min

Total cycle time =3.07 + 1.6 min =4.67 min

Estimated production =17.9 × 50/60 x 60/4.67 =192 BCM/h

# 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 =17.9 BCM from Example 4-8

Effective grades from Example 4-8:

Haul =+1.0%

Return =+9.0%

Turnaround =+5.0%

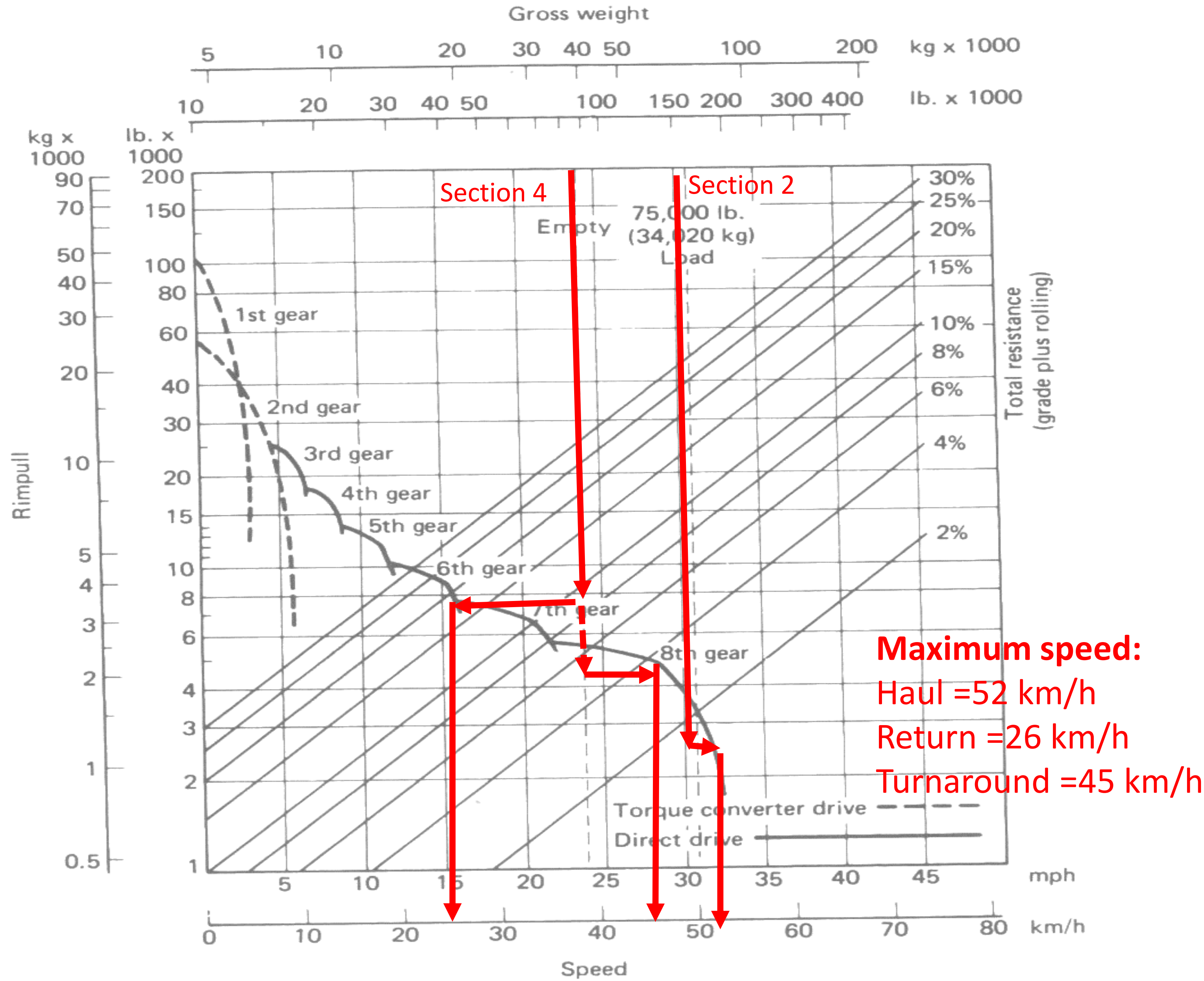
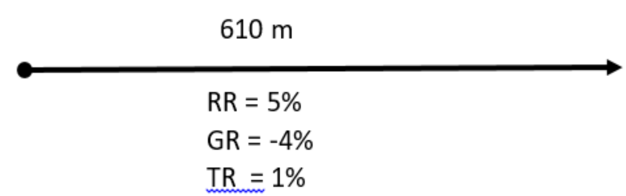



**Figure 4–2** Wheel scraper performance curve. (Courtesy of Caterpillar Inc.)

**Table 4-3** Average speed factors

| Length of Haul Section (ft) | Length of Haul Section (m) | Starting from 0 or Coming to a Stop | Increasing Maximum Speed from Previous Section | Decreasing Maximum Speed from Previous Section |
|---|---|---|---|---|
| 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 |

Haul route



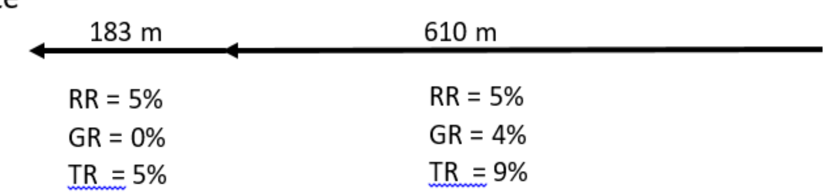

Average speed factor (Table 4-3):

Haul $= (\text{Case 1})^2 = 0.86 \times 0.86 = 0.74$

Return $= 0.86$

Turnaround $= 0.68$

Return route



# EXAMPLE 4-9

Average speed:

Haul = 52 × 0.74 = 38 km/h

Return = 26 x 0.86 = 22 km/h

Turnaround = 45 x 0.68 = 31 km/h

Travel time:

Haul = 610/(38 ×16.7) = 0.95 min

Return = 610/(22 ×16.7) = 1.75 min

Turnaround = 183/(31 × 16.7) = 0.36 min

Total = 3.06 min

Fixed cycle = 1.6 min (Example 4-8)

Total cycle time =4.66 min

Estimated production = 17.9 × 50/60 x 60/4.66 =192 BCM/h

# EXAMPLE 4-9

- 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.

# Push-Loading

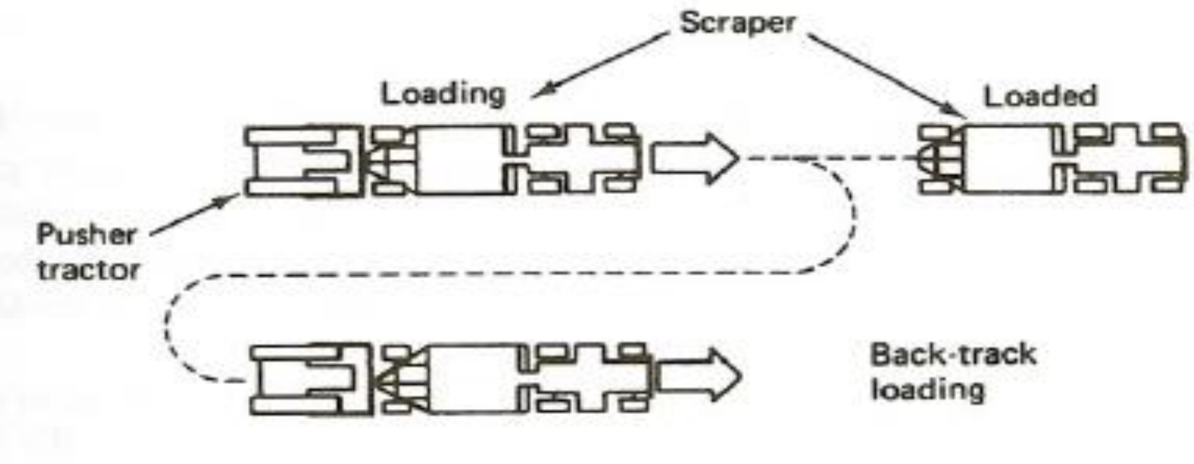
- Wheel scrapers require the assistance of pusher tractors to obtain maximum production, except for elevating and push-pull scrapers
- The three basic methods of push-loading scrapers are illustrated in Figure 4-22.

# Push-Loading

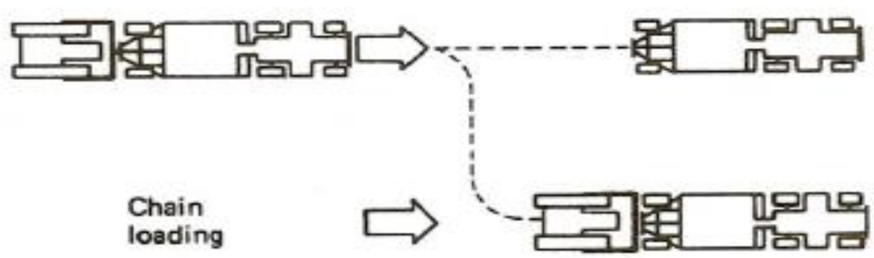
https://www.youtube.com/watch?v=UYZYPIWBl84

**Methods of push-loading scrapers**

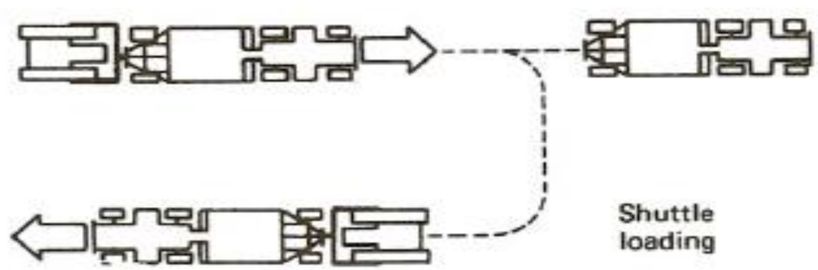
**1-The back-track method**: is the most commonly used since it permits all scrapers to load in the same general area. However, it is also the slowest of the three methods because of the additional pusher travel distance.



**2- Chain loading**: is suitable for a long, narrow cut area.




**3- Shuttle loading**: requires two separate fill areas for efficient operations.



# Push-Loading

- 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.

# Push-Loading

- Tandem pushing
  - involves the use 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
  - It 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

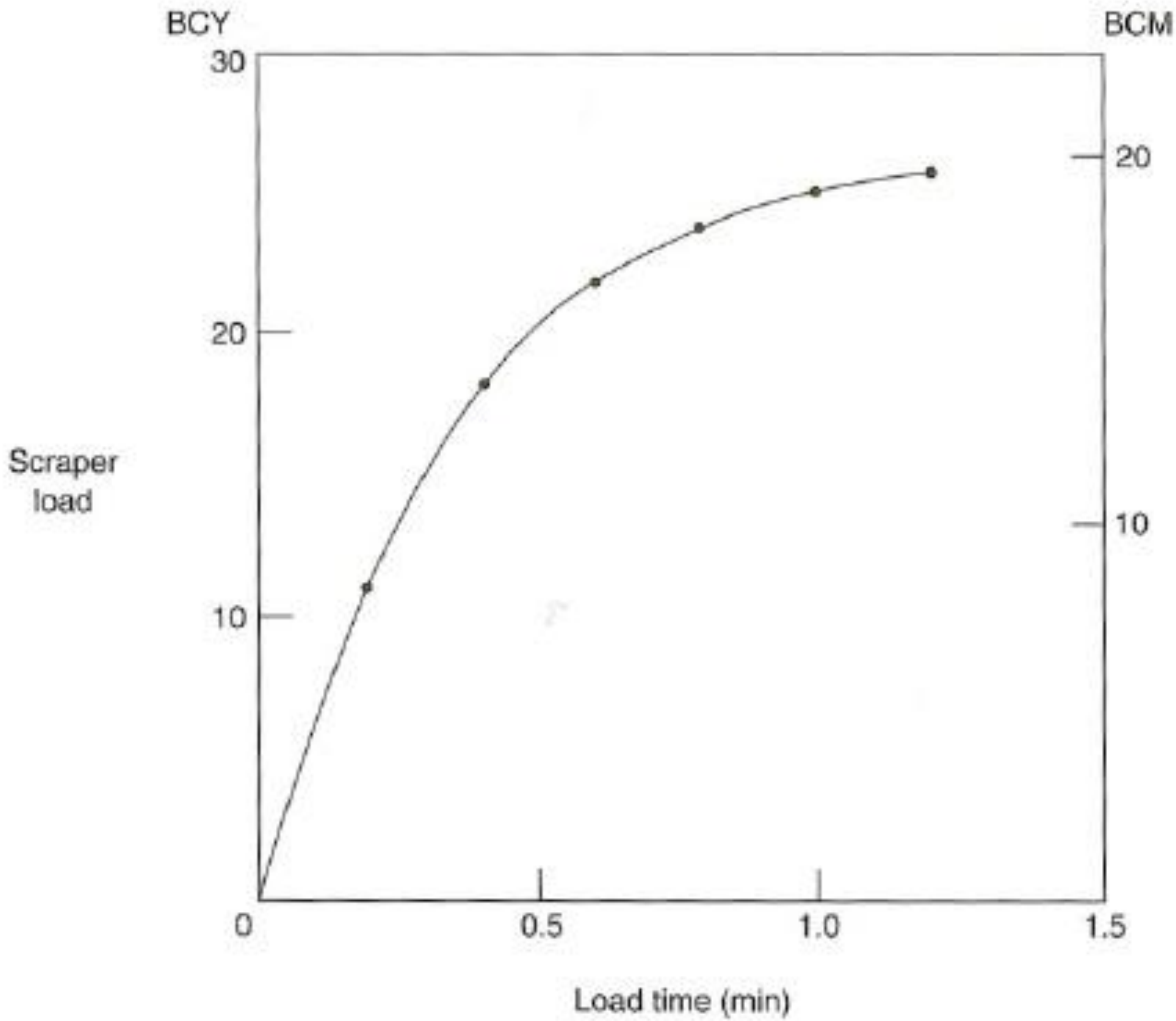
- In field studies performed by Caterpillar Inc. it was found that the scraper loading time which yielded maximum scraper production in a given situation was usually less than the loading time required to obtain the maximum scraper load (Maximum load vs. Maximum production).
- Caterpillar called the loading time which yielded maximum production the *optimum load time.*

Maximum load
Full load → Cycle time ↑ Production ↓

# Optimum Load Time
# Graphical Method

- 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).
  - The slope of the load growth curve at any loading time corresponds to the rate of loading at that time.

**FIGURE 4-23:** A load growth curve.



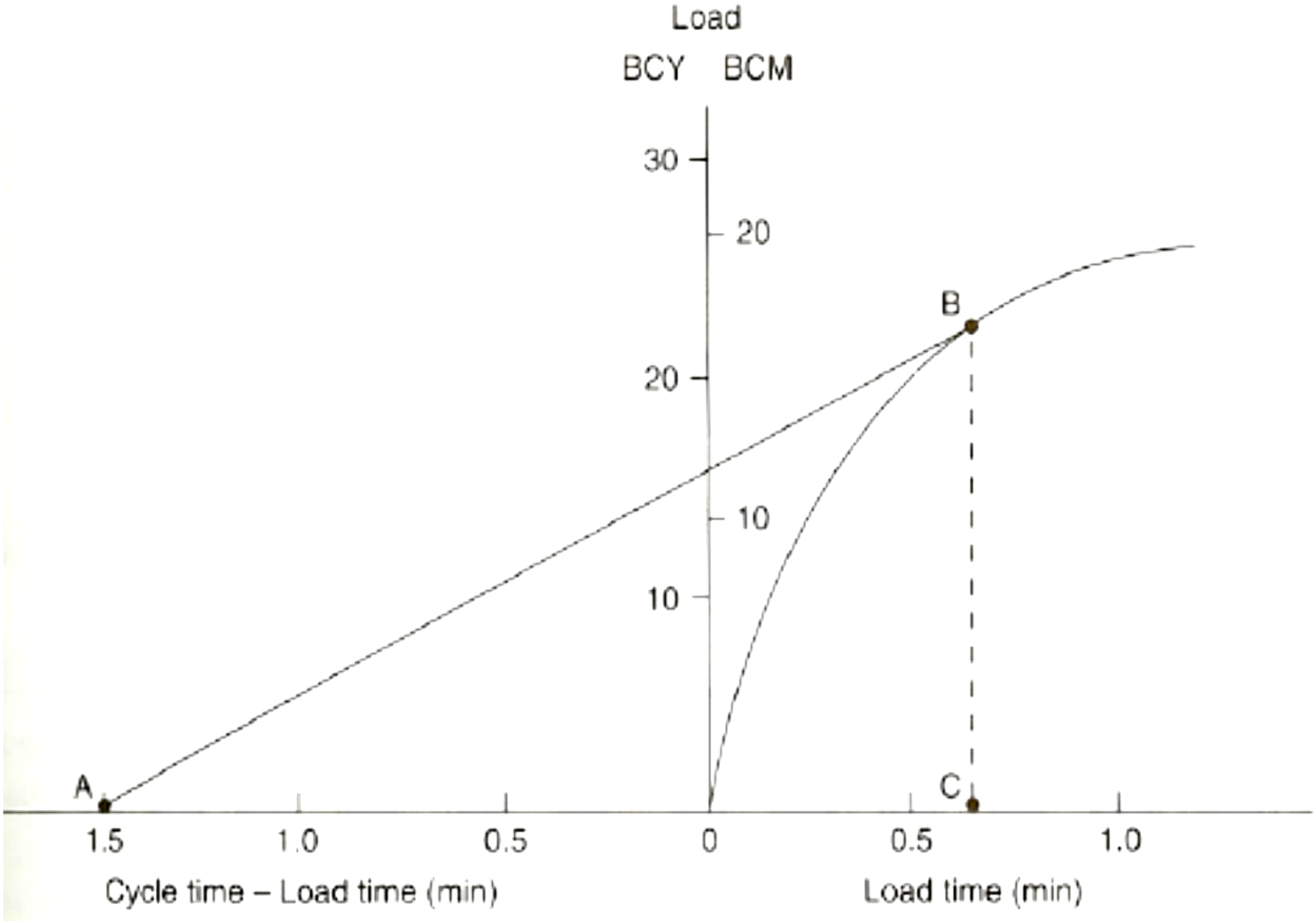
# Optimum Load Time

- 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 cycle time less loading time".
  - Finally, draw a tangent to the load growth curve from Point A intersecting the curve at Point B.

# Optimum Load Time

  - 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.

# **FIGURE4-20:** Finding the optimum load time.



# Optimum Load Time

## Calculation Method

## Example

What is the optimum load time for a scraper using the following data: cycle time less load time 4 minutes; efficiency 55 min/hour; relationships between time of loading and the volume of load are as follows:

| Load time (min) | 0.4 | 0.6 | 0.8 | 1.0 | 1.2 | 1.4 |
|---|---|---|---|---|---|---|
| Load (BCM) | 18.7 | 22.7 | 24.8 | 26.1 | 26.8 | 27.2 |

| Load time (min) | 0.4 | 0.6 | 0.8 | 1.0 | 1.2 | 1.4 |
|---|---|---|---|---|---|---|
| Load (BCM) | 18.7 | 22.7 | 24.8 | 26.1 | 26.8 | 27.2 |

# Solution

| Load time (min) | 0.4 | 0.6 | 0.8 | 1.0 | 1.2 | 1.4 |
|---|---|---|---|---|---|---|
| Cycle time less load time (min) | 4 | 4 | 4 | 4 | 4 | 4 |
| Cycle time (min) | 4.4 | 4.6 | 4.8 | 5 | 5.2 | 5.4 |
| Trips/hour | 12.5 | 11.95 | 11.46 | 11 | 10.58 | 10.19 |
| Load/trip | 18.7 | 22.7 | 24.8 | 26.1 | 26.8 | 27.2 |
| Production BCM/h | 233.75 | 271.41 | 284.17 | 287.1 | 283.5 | 277 |

Trips/h= 55 min / 4.4 min= 12.5 trips/ hr

Production = 12.5 x 18.7 = 233.75 BCM /h

Optimum load time = 1.0 min.

# Calculating the Number of Pushers Required (Calculating fleet production)

- 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.

  Number of scrapers served by one pusher =

  =Scraper cycle time / Pusher cycle time (4-11)

- The number of pushers required to fully service a given scraper fleet may then be determined from Equation 4-12.

  Number of pushers required =

  = Number of scrapers available / Number served by one pusher (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.
- Table 4-8 may be used for estimating pusher cycle 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 |

- 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.

  Production =

  (No. of pushers avail. /Required number) × No. of scrapers ×

  x Production per scraper (4-13)

  – In performing this calculation, use the precise number of pushers required, not the integer value.

# 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 (Equation 4-11):

Back-track = 6.5/1.5 =4.3 scrapers

Chain =6.5/1.0 =6.5 scrapers

Number of pushers required (Equation 4-12):

Back-track=9/4.3 = 2.1 = 3 pushers

Chain = 9/6.5 = 1.4 = 2 pushers

# 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 173 BCM/h.

## Solution

Number of pushers required to fully serve fleet = 1.4

Production= $(1/1.4) \times 9 \times 173 = 1112$ BCM/h (Eq 4-13)

# 6. 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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# Push-Pull Loading

- 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.

https://www.youtube.com/watch?v=pZa7Ts-OcAo

# Push-Pull Loading

- Advantages of this method of loading are:
  - 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.

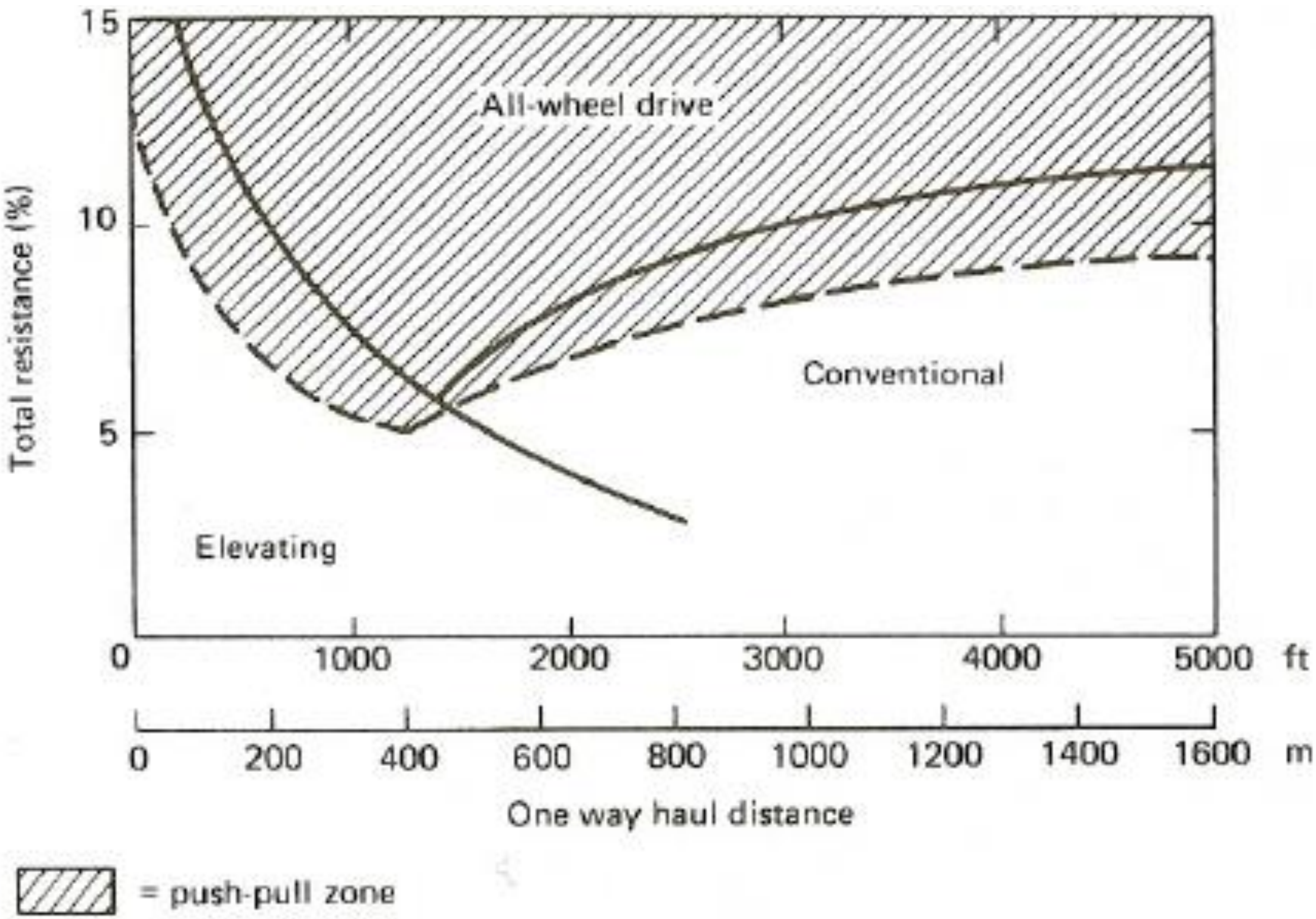
# Push-Pull Loading

- Disadvantage of this method of loading:
  - 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.

**FIGURE 4-25**: Scraper application zones.



# Job Management

- 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.

# Job Management

- 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 scarifies to loosen hard soils before attempting to load.
  - Have pushers give scrapers an adequate boost to accelerate units out of the cut.

# Job Management

– 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 payoff in increased scraper production.

# Job Management

- Make the haul road wide enough to permit high-speed hauling without danger. One-way haul roads should be utilized whenever possible.
- Keep the fill surface smooth and compacted to minimize scraper time in the fill.
- Boost scrapers on the fill if spreading time is excessive.

# Job Management

- 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**
- **Determining the Number of Haul Units Needed**
- **Job Management**

# Operation and Employment

- hauling (or the transportation) of excavation is a major earthmoving activity,
- There are many different types of hauling equipment available to the constructor. these are:
  - dozer,
  - loader,
  - scraper,
  - trucks,
  - wagons,
  - conveyor belts, and
  - trains.

# Operation and Employment

- 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.

# Operation and Employment

- 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.

# Operation and Employment

- 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, and
    - be equipped with standard or rock bodies,

# Operation and Employment

- 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.

https://www.youtube.com/watch?v=BjRVBX3r-JA

# Operation and Employment

- Wagons are tractors equipped with earthmoving semitrailers.
  - Wagons are available in end-dump and side-dump models as well as the more common bottom-dump model.
  - Bottom-dump models are preferred for moving earth and crushed rock because of their ability to dump and spread while moving at a relatively high speed.

# Determining the Number of Haul Units Needed

- 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.

**TABLE 4-9**: Spot, maneuver and dump time for trucks and wagons (min)

| | Bottom Dump | Rear Dump |
|---|---|---|
| Favorable | 1.1 | 0.5 |
| Average | 1.6 | 1.1 |
| Unfavorable | 2.0 | 2.5 |

# Determining the Number of Haul Units Needed

- Loading time should be calculated by the use of Equation 4-14 or 4-15.

Load time =

Haul unit capacity / Loader production at 100% efficiency (4-14)

Load time =

Number of bucket loads × Excavator cycle time (4-15)

# Determining the Number of Haul Units Needed

- 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.

# Determining the Number of Haul Units Needed

- 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.

Number of haulers required ($N$) * =

Haul unit cycle time / load time (4-16)

*Number of haulers served by on loader

# Determining the Number of Haul Units Needed

- 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).

# Determining the Number of Haul Units Needed

- 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.

# Determining the Number of Haul Units Needed

- 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 have to wait for a haul unit.

# Determining the Number of Haul Units Needed

- 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.
  - Expected production =

*(Actual number of units / N )** Excavator production (4-17)
(if no. units available is less than *N)*

# 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 =283 BCM/h
- Job efficiency=0.75
- Truck capacity =15.3 BCM
- Truck cycle time, excluding loading = 0.5 h

# EXAMPLE 4-12

## Solution

(a) Load time = 15.3/283 = 0.054 h (Eq 4-14)

Truck cycle time =0.5 + 0.054 =0.554 h

Number of trucks required = 0.554/0.054 = 10.3 = 11 (Eq 4-16)

Expected production = 283 × 0.75= 212 BCM/h

(b) With nine trucks available,

Expected production = 9/10.3 × 212 = 186 BCM/h (Eq 4-17)

# 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.

# Job Management

- 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.

# Job Management

- 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.

# Job Management

- 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.

# Job Management

- 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.

# Job Management

- 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.