Topic 2 Section 2

Determine Resource Requirements

Contents

What are Resources?

Resources are the materials, plant, equipment and people that must be managed so that they work together to create an outcome or product. In the construction industry, this is usually a building, road, or other structure.

The term 'resources' is therefore fairly broad. In a construction, job, it may include or refer to:

- people (human resources or labour)
- materials (consisting of or derived from natural resources, such as stone or timber, or synthetic products)
- plant and equipment (mechanical and/or motorised devices that we use to place and modify materials as part of the job).

The essential point is that any and all resources we use on a construction job cost money. To complete any construction job, we therefore need to:

- identify the required resources
- obtain enough resources to meet the needs of the job
- manage the resources, to ensure that we put them to their best use and avoid waste.

Estimating Productivity

What is Productivity?

Productivity is a statement, usually a number, that tells us what outputs a person or machine can achieve in a given amount of time. Outputs may include amount of dirt shifted, area of ground compacted, or number of bags of cement unloaded from a truck. The amount of time may be minutes, hours, days or weeks, depending on the task being performed. For example:

- an excavator's productivity may be 100 cubic metres of dirt shifted per hour
- a compactor may treat 5000 square metres in a day
- a person may unload 20 bags of cement from a truck per hour.

Productivity is an essential consideration when we are estimating how long a job will take or how much it will cost.

The following discussion is about ways of estimating the productivity of machines and labour.

Estimating the Productivity of Machinery

To understand how productive a machine is, we need to first consider six basic factors:

- time
- materials
- carrying capacity of plant
- efficiency of plant
- power required
- power available.

Time

From the job documents and works program, you will be able to calculate how many cubic metres of earth must be moved per working hour to complete the job on time. For example—

A supervisor has 6 weeks to move 80 000 bank m^3 of earth.* He has loaders, trucks and graders and plans to work an eight-hour day, five days a week. The number of hours available to complete the job is 240, i.e. 6 weeks of 40 hours each.

The required overall productivity therefore is, $\left(\dfrac{80\,000}{240}\right)$ m^3/h

$$= 333.3\ m^3/h$$

* For an explanation of the differences between bank, loose and compacted cubic metres, see later in this section.

Before he knows if he can accomplish this hourly rate, he needs to know how much per hour he can move with the available equipment. The best way to do this is to know the productivity of each machine. (Outputs of specific machines will be covered later).

For example, the job of the machine is to move 80 000 bank m^3 of earth. It will need to perform four basic functions:

- load
- haul
- dump
- return.

To complete the job, the various items of machinery will need to pick up the earth at the load point, move it to the dump point, offload it at within the required delivery area, and return to the pick-up point for the next load, repeating these steps as many times as it is necessary to move the 80 000 m^3.

These four functions are known as a cycle of operations, and exist on most construction jobs. Each will vary in nature and may last for a longer or shorter time from one job to another.

For the purpose of calculating the time taken for a machine to complete one cycle of operations, we can group road-making plant and equipment under three headings:

- Primary plant
- Secondary plant
- Static plant.

Primary Plant

These are machines that do not depend on receiving material from other machines. Their capacity fixes the rate at which the work can progress. In construction work, major-role machines include:

- dozers
- scrapers
- excavators
- graders.

Secondary Plant

These are machines that depend on the work of primary plant, or on each other. They are selected in accordance with the output of the primary plant, and include:

- rollers
- compactors
- trucks.

Static Plant

Static units of equipment (which may be either major or secondary machines) cannot move under their own power, but must be moved or carried to and from the works site by other machines. Static units may be used in quarries or borrow pits, or may work on a job site in a static situation. They include:

- crushers
- vibratory screens
- Air Trac drill rig
- compressors
- generating sets.

Balancing Primary and Secondary Plant

The usual procedure when selecting plant is to first decide on the primary machine that gives the required output. After this, select the secondary plant (considering both their number and size) so that they match, as far as possible, the output of the primary machine.

By using this approach, we can ensure that the various plant items are balanced. This means that the outputs of the major and secondary role machines are not too far ahead of, or behind, each other.

Cycle Time

The cycle time is the time taken for one round trip.

Since time means money, it is important for people who are responsible for managing plant to ask:

- How many minutes will it take for one machine to make one round trip?
- How long will it take to get the job done?

Every machine (including static plant such as a vibratory screen) has a cycle of operation, but the progress of the whole project will depend on the output of key machines.

Cycle time for mobile equipment is the time required for a machine to obtain its load, move to the dump location, dump the load, and return to the loading point.

Cycle time for static plant is the time taken in setting up, carrying out the operation, and then proceeding to the next location.

On any earthmoving job, mobile equipment moves according to a regular pattern (e.g. for scrapers or trucks, the pattern is load, haul, dump and return). Cycle time is the amount of time it takes a machine to complete one circuit of these operations.

In the case of dozers, the cycle would be pushing forward, stopping, backing-up and stopping again. In the case of wagon drills, the cycle would be setting up, drilling, withdrawing the drill and moving to the next drill position.

For mobile equipment, the cycle time consists of two parts: fixed time and travel time.

Fixed time is not dependent on the distance moved. It is the time taken for operations such as:

- spotting the machine in the right place for loading
- loading
- turning
- dumping
- reversing direction of travel; gear changes, etc.

These cycle segments are fairly constant regardless of the length of haul and return.

Travel time is time spent on the haul and return portions of the cycle. The time varies with the distance and condition of the haul road between the loading area and the fill. Travel time depends on:

- 'lead' or distance carted
- machine weight
- rolling resistance
- grade resistance or assistance
- traction
- useable pull
- speed.

We can make the estimating procedure much simpler by considering fixed time and travel time separately. Most manufacturers publish fixed-time constants for their equipment, based on actual field studies. While these constants are intended to serve only as a guide, we can use them in estimating fixed times.

Recommended practice is to calculate cycle times before starting an operation, then check them with a stop watch on the job after work has commenced.

Cycle time determines the number of trips per hour, and the supervisor should try to get as many trips per hour as possible from each item of plant. This means keeping cycle times to a minimum.

Reducing Cycle Times

The following practices will help to minimise cycle time.

To reduce fixed time—

- Whenever possible, set up a borrow pit so that the major-role machine (e.g. a scraper) is working downhill when loading the secondary-role machines.
- Eliminate waiting time in the cut by matching scrapers with pushers in the correct ratio for the job, and by adjusting load time as haul distances and job conditions change.
- Pushers should be equipped with rippers. In some cases, ripping the soil or rock prior to loading is an absolute 'must'.

Maintaining a haul road

To reduce travelling time—

- Lay out haul roads carefully. Job layout is one of the most important aspects of an earthmoving project. Even though a straight line is the shortest distance between two points, sometimes it is better to detour around hills and rough terrain.
- Maintain haul roads continually. Haul road maintenance is usually a full-time operation for a grader. Good haul roads are essential.

Cycle times for the more common types of equipment used in construction works will be considered later in this course.

Materials

Type of Material

The size and type of plant used must suit the type material being handled; e.g. a loader and rock trucks would be suitable for moving blasted rock.

If the plant is not appropriate to the material, outputs will be low and damage to the machine may result. For example, moving poorly fragmented rock with self-propelled scrapers will be slow and costly, and may cause damage to tyres and cutting edges.

Clays and loamy material are easy to work and can be dozed or loaded into scrapers in their natural state. Other materials, such as rock, must be ripped or blasted to loosen them before they can be moved.

Weight (Mass)

The supervisor must know the approximate weights of the various materials used on the job. He or she cannot estimate whether the equipment can do the work, unless the weight of each cubic metre is known.

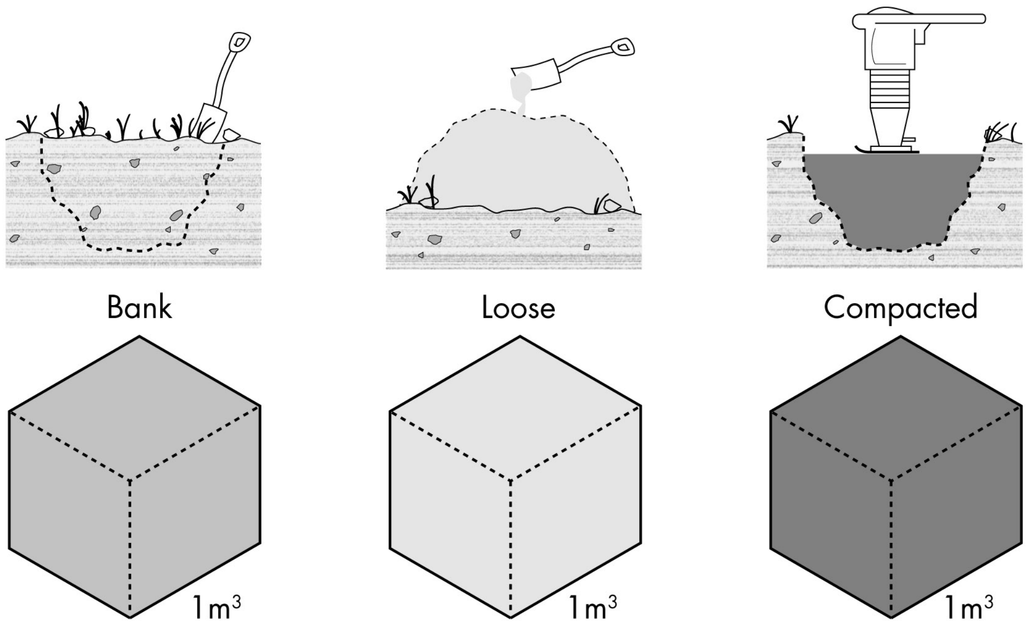
A supervisor should always check the load limits of equipment before starting the job. For example, if using trucks to transport wet gravel, the supervisor may find that the load limit is less than a full truck-load. However, if the trucks are shifting lightweight materials, such as dry soil, it may be possible to fill every truck without exceeding the load limit.

The weight of the material affects the way a scraper will load, a bulldozer will push or a grader will cast material. The heavier the material, the greater the effort required to move it. Some materials (e.g. rocks, wet clay and loose dry sand) may be difficult to load or unload, resulting in low output.

The ability of earthmoving equipment to turn, manoeuvre and haul in high speed ranges is directly influenced by weight. As long as you do not exceed the weight and volume capacities of the machines, you will obtain satisfactory performance.

Soil in its natural state has been weathered and has had time to settle into place; it therefore contains few air voids or spaces. When in this undisturbed state, its volume is referred to as 'bank', 'solid' or 'in place' cubic metres. When disturbed, the soil bulks or swells and is referred to as a 'loose' volume. When the loose soil is placed and compacted, its volume is reduced and is known as the 'compacted' volume. Therefore:

- A bank cubic metre is one cubic metre of material as it lies in its natural state, i.e. measuring 1m x 1m x 1m.
- A loose cubic metre is that volume of material that measures 1m x 1m x 1m after being excavated from its natural (bank) position and allowed to expand.
- A compacted cubic metre is a volume of material that measures 1m x 1m x 1m after being placed in a fill and compacted.



The density of a material, whether bank, loose or compacted is the weight of one cubic metre; it is stated as a number of kilograms (kg) per cubic metre (m^3). The density of water is 1000 kg/m^3.

The table on the next page shows:

- The densities of various materials in the bank state
- Densities of the same materials in the loose state
- Percentage swells, load factors and angles of repose of the materials (see later).

The first two columns of the table show how much the densities of materials may vary. For example, at 3130 kg/m^3, the density of massive rock may be more than three times that of water.

The values in the table are given as a guide for estimating purposes. On the job, you can check the estimated amount against the actual amount of a material by:

- measuring up a cutting or excavation, and the fill to which the material is led
- measuring the capacity of the hauling vehicles
- tallying the number of loads required to shift the measured quantity.

Swell

Swell is the increase in volume of the material when it is removed from the natural state. It is expressed as a percentage of the bank volume. For example, if a material has a swell of 25%, it means that one cubic metre of the material in the bank state will occupy 1.25 m^3 in the loosened state.

Load Factor

Load factor is the percentage decrease in the density of a material from its natural state to the loose state.

$$\text{Load Factor} = \frac{\text{kg per m}^3\text{ (loose)}}{\text{kg per m}^3\text{ (bank)}}$$

$$\%\ \text{Swell} = \left[\left(\frac{1}{\text{Load Factor}}\right) -1\right] 100$$

The table (below) gives the properties of materials commonly used in construction. Using dry clay as an example, we can calculate the load factor and swell as follows:

$$\left.\begin{aligned}\text{Density in bank} &= 1310\ \text{kg/m}^3 \\ \text{Density loose} &= 1048\ \text{kg/m}^3\end{aligned}\right] \text{From table below, for dry clay}$$

$$\therefore\ \text{Load factor} = \frac{1048}{1310}$$

$$= 0.80$$

$$\%\ \text{Swell} = \left[\frac{1}{0.80} - 1\right] 100$$

$$= 25\%$$

Table of Material Properties

Material	Density		Swell %	Load factor	Approx. angle of repose
	kg/bank m³	kg/loose m³			
Clay – dry	1310	1048	25	0.80	1:2 (27⁰)
– light	1660	1278	30	0.77	1:2 (27⁰)
– heavy/wet	1870	1402	33	0.75	1:1 (45⁰)
Earth – dry loam	1600	1280	25	0.80	1:2 (27⁰)
– moist	1735	1388	25	0.80	1:1 (45⁰)
– wet	2030	1624	25	0.80	1:2 (27⁰)
Earth, sand and gravel	1885	1602	18	0.85	1:2 (27⁰)
Earth and rock	1565–2000	1205–1540	30	0.77	1:2 (27⁰)
Gravel – dry/ loose	1885	1678	12	0.89	1:2 (27⁰)
– wet/loose	2190	1927	14	0.88	1:2 (27⁰)
Limestone	2590	1528	70	0.59	1:2 (27⁰)
Rock – crushed	1920-2670	1420-1976	35	0.74	1:2 (27⁰)
– massive	2605-3130	1745-2097	50	0.67	1:1 (45⁰)
Sand— dry	1925	1713	12	0.89	1:3 (18⁰)

Material	Density		Swell %	Load factor	Approx. angle of repose
	kg/bank m³	kg/loose m³			
– wet	2135	1857	15	0.87	1:2 (27⁰)
Sand and gravel – dry	2000	1760	14	0.88	1:2(27⁰)
– wet	2335	2008	16	0.86	1:2 (27⁰)
Shale	1770	1327	33	0.75	1:1 (45⁰)

Note!
Weights shown in the table are averages. Actual weights are affected by moisture content, grain size, and other factors. Tests must therefore be carried out to determine exact material characteristics.

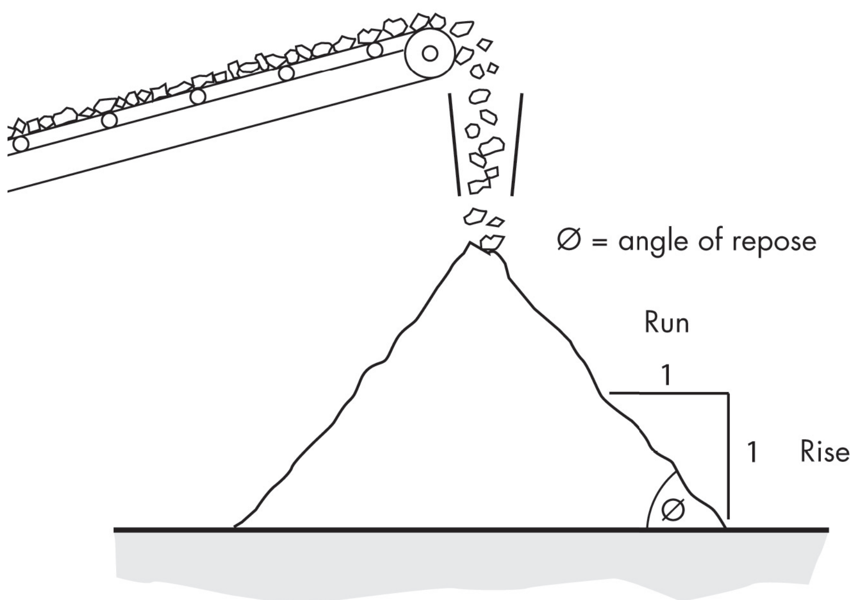
Angle of Repose

A stockpile is formed by tipping the material and allowing it to fall freely to the ground. The angle of repose of a material is measured as the angle that the side of the stockpile makes with the ground. It is the angle at which the material naturally tends to rest on a level surface, as shown below. The angles of repose of common construction materials vary between 20° and 45°.

The slope of material in a stockpile may be written in two ways:

- as an angle, in degrees
- as a fraction or a ratio.

To express an angle of repose as a fraction:



$$\text{Fraction} = \frac{\text{rise}}{\text{run}} = \frac{\text{vertical distance}}{\text{horizontal distance}}$$

In the example shown (a pile of shale), the fraction is $\frac{1}{1}$

To express an angle of repose as a ratio:

Ratio = 1 (Rise):1 (Run) = 1:1

Other common ratios of materials are 1:2 and 1:3.

The convention is that the Rise (vertical distance) is always divided by the Run (horizontal distance). This is the same as the convention used for expressing slopes and gradients (see dozer example, page 18).

Load Calculations involving Bank and Loose Volumes

The following calculations involve a self-loading scraper of 16.8 m^3 heaped capacity being used to move 200 bank m^3 of dry loam. The aims are to calculate:

- Weight of a heaped load (loose).
- Amount of loose material to be moved.
- Amount of swell (in m^3)

The table gives the following properties of dry loam:

- Density = 1600 kg/m^3 bank
- Swell = 25%
- Load Factor = 0.80

Calculating weight of a heaped load—

Each heaped cubic metre in the scraper bowl represents 0.8 of a bank cubic metre. Therefore:

16.8 m^3 loose x 0.8	=	13.4 m^3 of bank
Therefore weight of load (kg)	=	(13.4 m^3 x 1600 kg/m^3)
	=	(13.4 x 1.6) tonnes (1000 kg = 1 tonne)
	=	21.44 tonnes

Calculating amount of loose material to be moved—

Loose material to be moved	=	Bank volume divided by load factor
	=	(200/0.8) loose m^3
	=	250 loose m^3

Calculating amount of swell—

Swell	=	(250–200) loose m^3
	=	50 m^3

Calculations involving Loose and Compacted Volumes

When soil placed in a fill is thoroughly compacted by rolling, it will shrink. The amount of shrinkage that soil will experience depends upon:

- soil character
- structure in the bank
- thickness of fill layers
- weight and type of roller.

Measurement in the fill is described as compacted cubic metres or 'cubic metres after compaction'.

Calculations commonly carried out on compacted volumes include compaction factor and shrinkage ratio.

$$\text{Compaction factor} = \frac{\text{Volume in fill}}{\text{Volume in bank}}$$

$$\text{Shrinkage ratio} = 1 - \text{Compaction factor.}$$

Maximum Dry Density

An alternative approach is to use maximum dry density (MDD). This measure depends on the fact that soils can be compacted to varying degrees, depending on their moisture contents. Generally, the degree of compaction (i.e. density) of a dry soil increases with increasing moisture content up to a certain point, beyond which it decreases as more moisture is added.

In short, MDD is a measure of the maximum mass per unit volume(density) that a given soil can achieve under compaction.

MDD is determined by laboratory test. The density of a soil over a range of moisture contents is measured, and is used to determine the moisture-to-density relationship for the particular soil. From this relationship the maximum density achieveable (for a standard, specified compactive effort), and the corresponding moisture content, can be identified. At this point, the soil is said to be at 100% MDD and the moisture content is known as the optimum moisture content. This is the moisture level construction crews try to achieve when compacting materials.

Materials in bank or loose states can be tested to determine respective densities and then related, as a percentage, back to MDD. These values can then be used to determine the changes in volume of materials between different states (i.e. between bank, loose and compacted). This approach is typically applied to quarry material used in construction.

An example of the use of MDD is shown in Case Study 16.

Carrying Capacity of Plant

Once the material has been loosened by excavation, it has to be handled and carried in a loose state. The capacity of the plant that carries or loads it (e.g. scrapers, trucks, and front end loaders) is therefore expressed in cubic metres of loose measure.

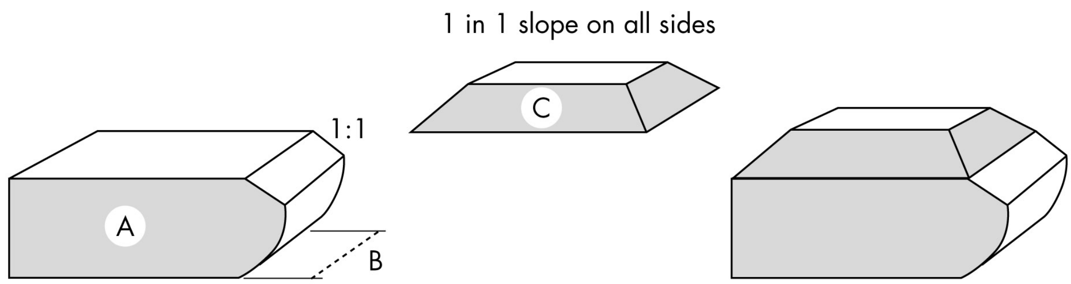
When calculating machine capacity, we need to understanding the terms ‘struck’ capacity and ‘heaped’ capacity:

- Struck capacity is the volume of loose material a container (such as a truck body or scraper bowl) can carry when filled exactly to level.
- Heaped capacity is the additional volume (of loose material) that can be carried above the struck capacity.

The drawings (below) show struck and heaped capacities for a scraper bowl and loader bucket, and how they may be calculated.

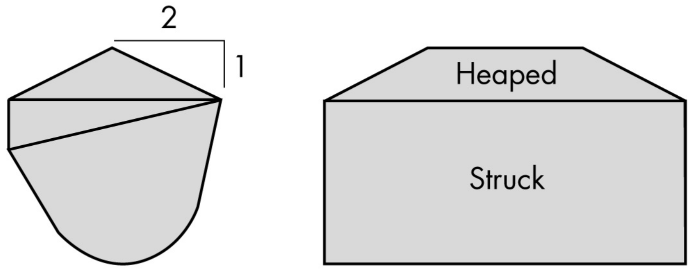
In practice, the numbers we use for heaped and struck capacities of machines are those specified by the machine manufacturer.

Scraper Carrying Capacity



Struck Capacity (A) + Volume ‘C’ = Heaped capacity (m^3 loose)
(Area ‘A’ x Width ‘B’)

Loader Carrying Capacity



The struck bucket capacity is the volume in the bucket obtained by drawing a straight edge across the bucket, with one end of the straight edge on the bucket cutting edge and the other on the top of the bucket back sheet.

The heaped bucket capacity is the volume in the bucket when the struck line is horizontal and the material is heaped on a 1-in-2 slope (see diagram). Generally, a loader is described by its bucket capacity, using heaped cubic metres.

For more information about the correct method for stating gradients of roads and angles of repose of materials, see Case Study 2 at the end of this topic.

Plant Efficiency

People and equipment cannot work 60 minutes out of every hour, because unavoidable delays occur. Plant production is therefore greatly dependent upon the efficiency of both machines and operators.

Factors that may affect the efficiency of a job are:

- The skill of the operator.
- Operator fatigue, depending on the number of hours worked, the breaks allowed and the conditions under which he or she is working.
- Unscheduled servicing and adjustment of equipment.
- Stops to allow blasting to take place.
- Provision for traffic.
- Haul road maintenance.
- Unbalanced 'helper' equipment such as graders, rollers and pushers.
- Unscheduled stops by the operator.

Operator Efficiency

Operator efficiency is the percentage equivalent to the number of minutes per hour that the machine is working at full efficiency (e.g. 45 minutes of efficient work per working hour is 75% efficiency).

The following table gives a guideline for operator efficiency:

Good	50 min/hr	83% efficiency
Average	45 min/hr	75% efficiency
Poor	40 min/hr	67% efficiency

Task Efficiency Factor

When planning a construction job, we always aim to avoid additional delays. However, the nature of the task, the local conditions at the site, or the type of machine in use will often involve the loss of additional time and result in reduced production.

We use a 'Task Efficiency Factor' to allow for such losses.

The table shows task efficiency factors for a number of machines.

Machines	**Task factor**				
	Length of pass in metres				
	50	**100**	**200**	**600**	**600+**
Grader in major role (i.e. no interference from other machines)	0.4	0.6	0.8	0.9	1.0
Grader in subsidiary role (i.e. spreading and shaping materials brought by other machines)	0.4	0.5	0.7	0.8	—
Rippers and scarifiers	0.5	0.7	0.8	1.0	1.0
Mix-in-place stabilisers	0.5	0.6	0.7	0.7	0.7
Towed rollers	0.5	0.7	0.9	0.9	1.0

Note!
For major-role machines such as scrapers, bulldozers and trucks, the task efficiency factor is normally 1.0.

Combined Efficiency Factor

By combining the task and operator efficiency factors, we can obtain a combined efficiency factor for the operation of the particular machine.

Combined efficiency factor = Task efficiency factor x Operator efficiency factor

Because the task and operator efficiency factors are both 1.0 or less, the combined efficiency factor cannot be more than one. In many cases, it is less than 0.75.

Calculating combined efficiency factor—

If we are operating a grader as the major-role item over passes of 200m and the operator is judged efficient for 55 minutes per hour, the combined efficiency factor is:

Combined efficiency factor	=	0.8 (from table above) x 55/60
	=	0.8 x 0.917
	=	0.7336

Power Required

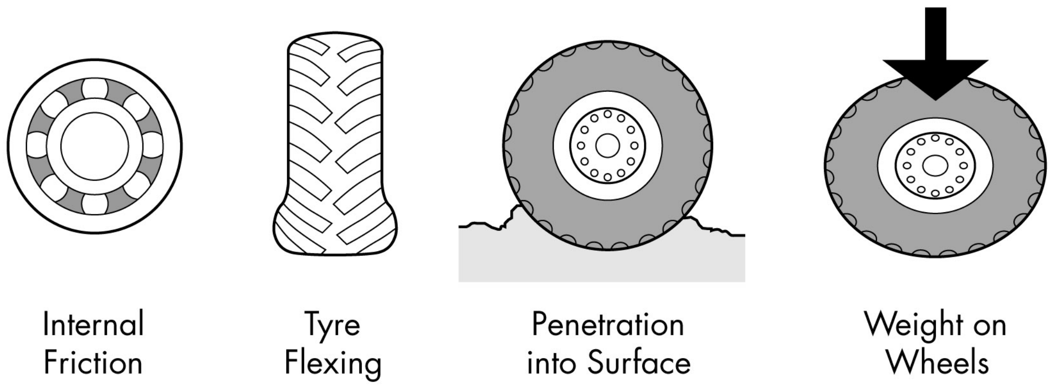
Power is required to pull or push a load. For example, when a truck hauls a load of material over a distance, the power of the prime mover must overcome the forces that resist movement. These forces are:

- rolling resistance
- grade resistance.

Rolling Resistance

Rolling resistance is the resistance offered to the movement of a wheeled machine over level ground. The vehicle will not move until this resistance has been overcome.

A number of influences combine to produce rolling resistance. The most significant, as shown in the illustration, are internal friction, tyre flexing, tyre penetration and weight on the wheels.



Factors Causing Rolling Resistance

Bearings and other mechanical components between the engine flywheel and the tyres on the ground resist movement to some extent. Internal friction is therefore the friction within the drive train.

As shown in the second drawing above, the sidewall and tread of the tyre become distorted as the tyre turns. This distortion, known as tyre flexing, contributes to rolling resistance.

The weight acting on the wheels (fourth drawing above) comes from the combined weights of the empty vehicle and the load.

If an earthmoving machine is well-maintained, the total effect of internal friction and tyre flexing does not change greatly. However, rolling resistance increases as the tyre penetrates further into the running surface (e.g. is the ground is soft and wet— see third drawing above).

Case Study 2 at the end of the topic shows how to calculate rolling resistance for a wheeled tractor. This example emphasises the point that machines have to supply much more push before they can do any useful work if access roads are not maintained, or the road surface cannot be drained and kept hard and dry.

Rolling resistance does not apply to track-type plant and equipment because they carry their own built-in, steel 'roads' with them. These are always hard and smooth. However, a loss of power does occur between engine and tracks, but this is allowed for in the drawbar (or 'horsepower') rating of a crawler machine.

The most important thing that can be done to reduce rolling resistance (and therefore, power requirements and costs) is to keep the road surface in a hard, smooth state.

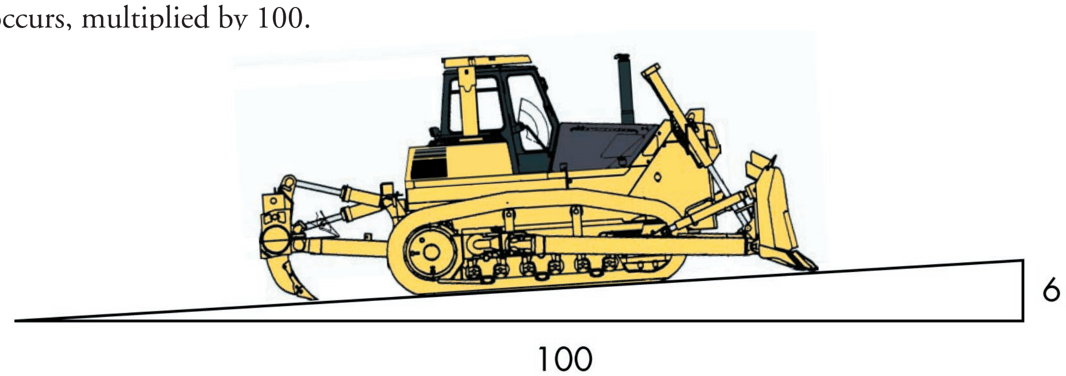
Grade Resistance and Assistance

Grade resistance is the force of gravity that a machine must overcome before it can move uphill (i.e. on unfavourable grades).

However, gravity may also work in favour of a machine (i.e. on favourable or downhill grades).

Grade resistance or grade assistance acts on the total weight of any unit of plant or equipment, whether it has tracks or wheels.

Both grade resistance and grade assistance are measured in the same way; i.e. as a percent slope. This is the vertical rise or fall, divided by the horizontal distance in which the rise and fall occurs, multiplied by 100.



Measurement of Grade

Example—

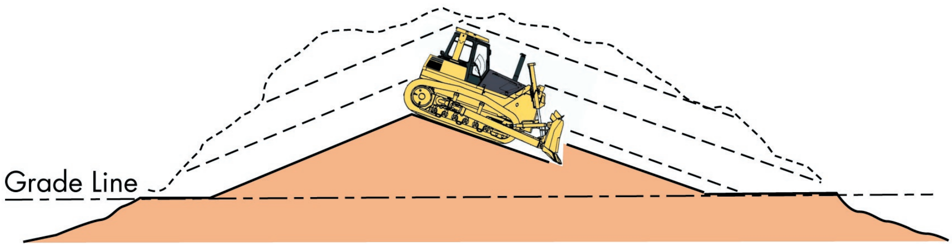
The drawing shows a dozer climbing a rise of 6m in a 100m horizontal distance. The slope is:

$$\left(\frac{6\text{m}}{100\text{m}} \text{ X } 100\right) \% = 6\% \text{ grade}$$

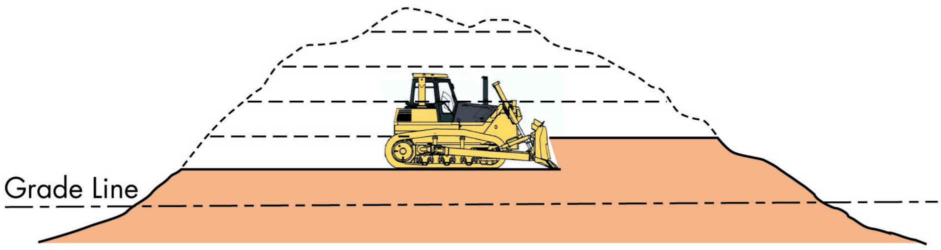
You will only be able to manage plant efficiently if you understand the effect of grade resistance or assistance on bulldozers, scrapers and trucks, as follows:

Grade Assistance and Resistance of Dozers

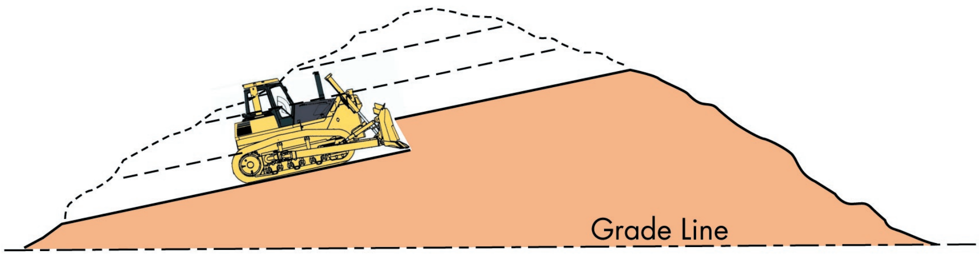
Downhill operation provides grade assistance, increasing the dozer output.



The rule with dozers therefore is, work downhill whenever practicable, to allow gravity to help the tractor power. Downhill working allows the spoil to roll ahead of the blade easily; this decreases the weight to be pushed.



When a dozer is working on the horizontal, gravity does not provide any assistance and it needs more power.



Do not work a dozer uphill. Gravity is working against the tractor; so more power is required for less work (i.e. we have grade resistance).

Grade Assistance and Resistance of Scrapers

Gravity assists in obtaining a heaped load quickly. It may sometimes eliminate the need for a pusher tractor where the scraper is not self-loading.

Loose rock, shale or sand, all of which tend to slide ahead of the blade, are exceptions. The operator will obtain better loading on the level or on a slight uphill grade.

Grade Assistance and Resistance of Trucks

The best approach is to plan the haul route so that the trucks are running on a downhill gradient wherever possible.

Total Resistance

Regardless of whether the haul route is uphill, downhill or level, rolling resistance is always present. To calculate total resistance, consider rolling resistance in conjunction with grade resistance or assistance. For example:

- When travelling uphill, a machine must overcome both rolling resistance and grade resistance.
- When travelling over level ground, a machine must overcome rolling resistance only.
- When travelling downhill, a machine must overcome rolling resistance but has grade assistance.

Case Study 3 at the end of this topic shows how the figure of 10 kg resistance per tonne of total machine weight may be used to calculate grade assistance or resistance.

Grade is especially important on earthworks, roads and borrow pits.

In practice, we generally avoid using uphill leads and, whenever possible, locate borrow pits at a higher elevation than the fill. This ensures that the grade of the haul road will help the loaded trucks or scrapers, permitting them to carry larger loads or travel at higher speeds.

Since the truck or scraper will be empty when returning from the fill to the borrow pit, the effect of the grade will be much less.

For reasons of braking and safety, however, downhill grades cannot be too steep.

Acceleration

While the machine needs power to overcome grade and rolling resistance, it also needs additional power to obtain acceleration. If this power is not available, the machine cannot increase its speed in any gear.

Experience has shown that if an excess power of 9 kW per tonne is available in the highest gear used on a particular haul, the machine will be able to deliver adequate performance.

Power Available

Once we know the amount of power required, the next step is to find out how much power will be available. In other words, how many kilograms pull can the machine provide?

Two factors determine the amount of power available. These are kilograms pull and speed.

Kilograms Pull

Power (expressed in kilowatts or kW) is the work the machine performs in a specified period of time, and is a constant value for any given vehicle. The formula shows the relationship between power, kilograms pull and speed:

Power (kW) = Kilograms pull x Speed

Since power remains constant, available kilograms pull will change as the speed varies. There are two alternatives:

- exert low pull while travelling at high speed (e.g. an empty scraper on a smooth, level, hard road)
- exert strong pull, while travelling at a slow speed (e.g. a track-type tractor ripping hard ground).

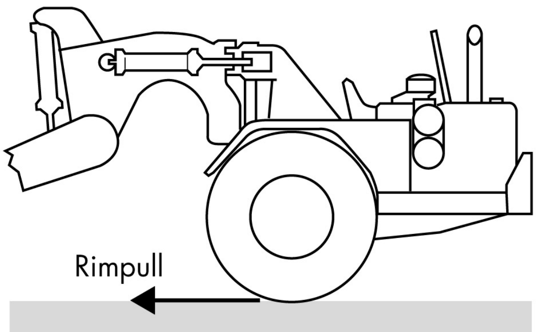
Despite these differences, both machines may have the same power. Kilograms pull will increase as speed decreases; and will decrease as speed increases.

The transmissions of earthmoving machines are designed to provide combinations of speed and kilograms pull that meet the requirements of different jobs. Each time the operator selects an operating gear, he or she will obtain certain speed and kilograms-pull combinations. First gear gives a slow speed, but strong pull; third gear gives more speed, but much less pull.

Machines equipped with torque converters allow operators to select a wider range of kilograms pull and speed combinations. (A torque converter is a device that spreads the load through a planetary gear set, rather than concentrating it on a single rotating shaft).

Rimpull

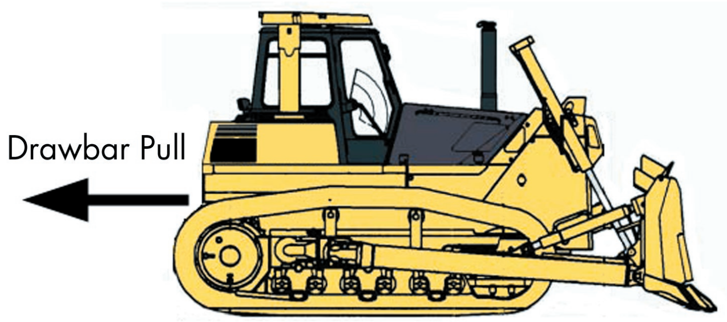
In the case of a wheel-type vehicle, pull is measured as rimpull, which is the force available between the tyre and the ground to propel the vehicle forward.



Rimpull of wheel-type vehicle

Drawbar Pull

For a track-type machine, the unit of measurement is drawbar pull, which is the force available at the point of attachment (i.e. the drawbar). This force is available either to pull the unit it is towing, or push material in front of the blade.



Drawbar pull of track-type machine

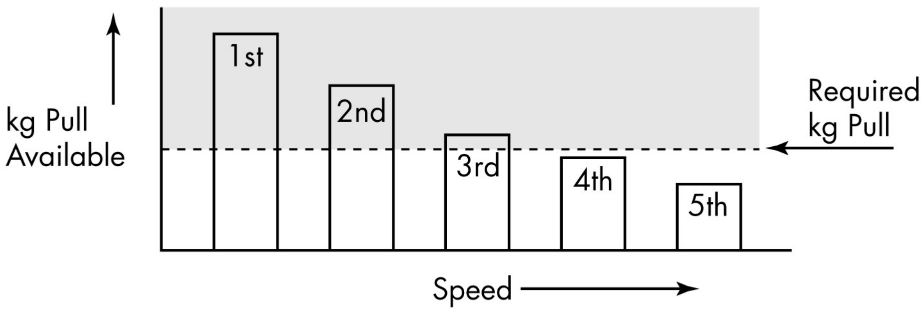
Maximum output is available only at maximum speed. The operator should work the machine at the highest speed (i.e. highest gear) that is consistent with the drawbar pull or rimpull required, and the safety of the machine and its operator. This means that operators must make full use of the available power of their machines.

To get maximum production, operators must be adequately trained and be properly directed by the plant supervisor.

Matching Required and Available Power

How fast can a machine haul a load? To answer this question, match the kilograms pull required (rolling resistance plus grade resistance) against the kilograms pull available (taken from the machine specifications sheet) and then select a reasonable operating gear. Select the maximum speed, if it is practical.

This selection process can be shown diagrammatically for a given job by a simple bar graph.



Bar graph (kilograms pull versus speed)

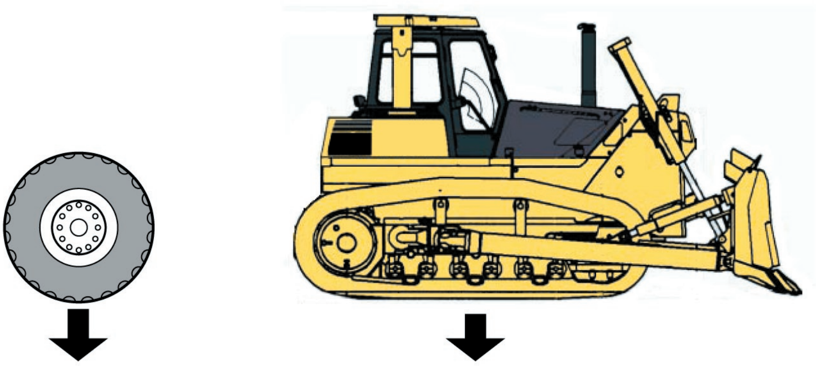
Case Study 4 shows the calculations used to match available power to required power.

Useable Power

Often it is not possible to use all the available power of a machine. Usable power is limited by traction, which is the gripping action of the wheels or tracks against the surface of the ground. Traction is important for all commonly used construction equipment, including:

- scrapers
- bulldozers
- trucks.

The gripping action between tracks or wheels and the surface varies according to the weight on the tracks or wheels and the type of surface over which the equipment operates.



Weight on wheels or tracks

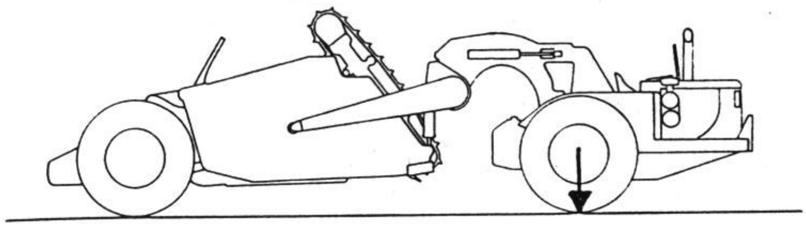
When tracks or wheels spin, there is insufficient traction.

The basic limitations on the pulling power of a machine are:

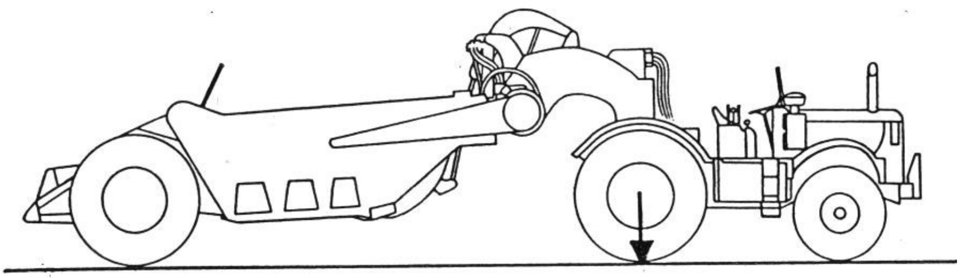
- self weight of the machine
- the weight on the driving wheels
- underfoot conditions.

No earthmoving machine can exert more pull (in kilograms) than it has weight on its drive wheels or tracks. This is reduced still further with a rubber-tyred machine, where the total all-up weight is distributed between the driving and non-driving wheels. It is only the weight that is placed on the driving wheels that counts as pull available to do the work.

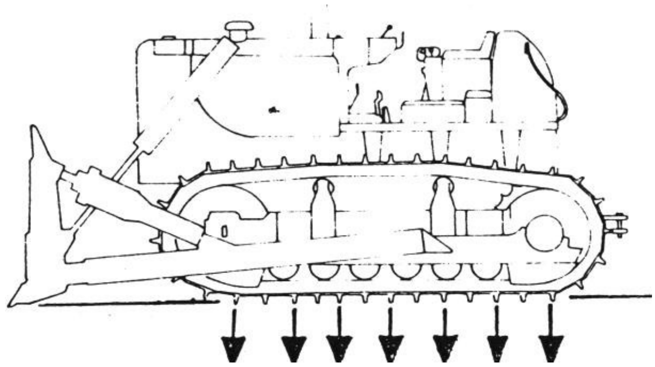
The following illustrations show how the weight available at the driving wheels or tracks varies according to the type of machine.



Weight on drive wheels of a two-wheel scraper— consult manufacturer's specification sheet or calculate as 60% of vehicle gross weight.

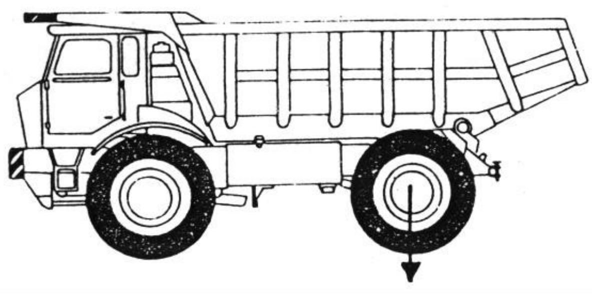


Weight on drive wheels of a tractor-scraper— consult manufacturer's specification sheet or calculate as 40% of vehicle gross weight.



Weight on drive wheels of bulldozer is equivalent to total weight of tractor.

Weight on drive wheels of a truck— consult manufacturer's specifications or calculate as 60% of vehicle gross weight.



Coefficient of Traction

We can use a number to describe the effect that the underfoot conditions are having on the machine. The number, called a 'coefficient of traction', is multiplied by the weight of the machine on the driving wheels or tracks, to determine the amount of usable pull which can be exerted before the wheels spin or the tracks slip.

The table shows various types of underfoot conditions and their approximate coefficients of traction.

Type of underfoot condition	Approximate Coefficient of Traction	
	Rubber tyres	Track
Dry clay and loam	0.55	0.90
Wet clay and loam	0.45	0.70
Dry sand	0.20	0.30
Wet sand	0.40	0.50
Quarry pit	0.65	0.55
Gravel road (loose)	0.36	0.50
Firm earth	0.55	0.90
Loose earth	0.45	0.60
Smooth, dry hard surface	0.90	0.45
Deep liquid mud	**	*

* Can operate in depths up to top of track
** Cannot operate.

Use the following formula to determine the amount of useable pull:

Useable Pull = Coefficient of traction x Weight on drivers
(where drivers are either the driving wheels or tracks.)

Case Study 5 shows how to use coefficient of traction to calculate useable pull.

Effects of Altitude on Power Available

You should be aware that available power may be limited by altitude, as well as other factors. As altitude increases, the air becomes less dense. Above about 1000 metres, the decreased density of the air may cause a reduction in the power output of some engines. The higher the altitude, the greater this loss is likely to be.

There are only a few areas, e.g. Atherton Tablelands, Granite Belt, where construction would take place on a regular basis at altitudes greater than 1000m. In all other parts of Queensland, we can assume that altitude does not affect power available.

Determine Plant Requirements

This section covers the determination of plant requirements, according to the type of plant required for the job. Plant is considered under the following sub-headings:

- bulldozers
- loaders
- trucks
- scrapers
- machines that operate in passes
- general comments on estimating plant requirements.

Bulldozers

Bulldozer Cycles

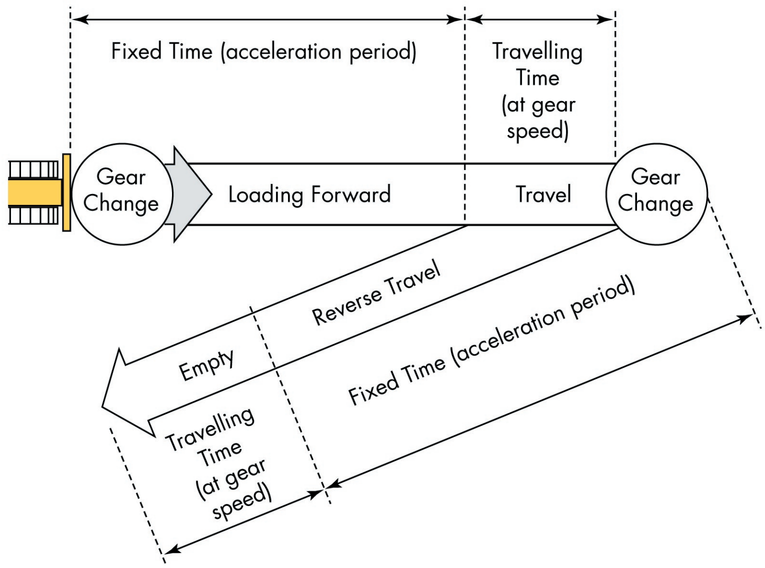
On an earthmoving task, i.e. excavating, stripping or backfilling, the bulldozer cycle consists of:

- getting into gear
- accelerating
- travelling forward, using the blade to excavate and push the load as it goes
- depositing the load at the required point
- changing gear
- accelerating and travelling backwards to the starting point in a high reverse gear.

This is the cycle of operation which a crawler or rubber-tyred bulldozer repeats continually. It is represented diagrammatically below. As shown, it includes both fixed and travelling time.

Bulldozer Fixed Time

Experience has shown that the maximum fixed time taken to shift into gear and accelerate to gear speed is 30 seconds for crawler tractors and 60 seconds for wheeled tractors. For power-shift machines, the time for crawler tractors would be about 15 seconds and 30 seconds for rubber tyred machines.



Typical Bulldozer Cycle

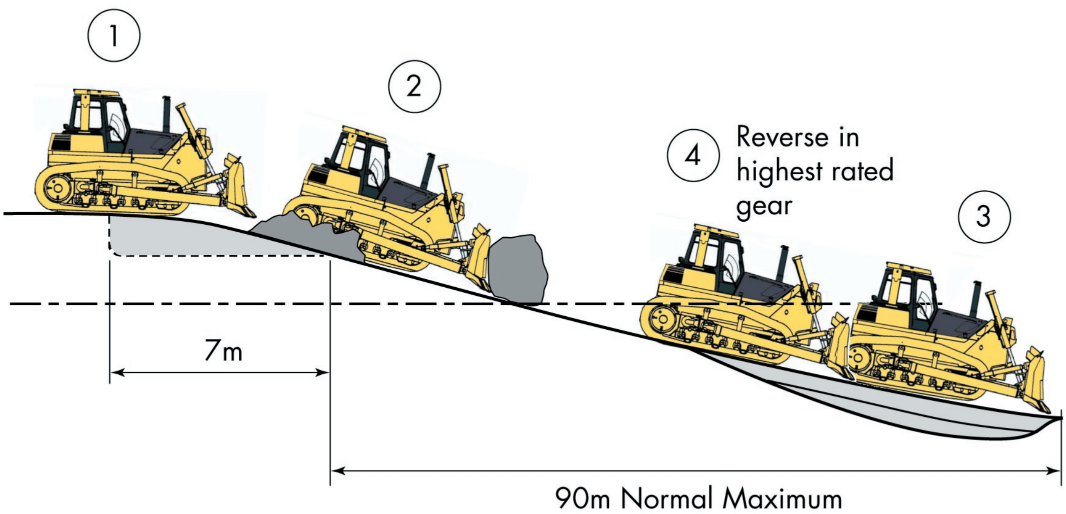
During this time, the tractor moves a distance, depending on the gear used. This has to be allowed for in any estimate of cycle time.

Case Study 6 shows how to calculate distance travelled in fixed time for a crawler tractor.

Typical Bulldozer Operating Cycle

The drawing shows the typical method of operation of a bulldozer engaged in cutting and filling a site. Maximum operating length for most bulldozer cycles is 90m.

1. Use enough passes to fill blade in 7m in first gear, float blade and change up
2. Roll heaped material ahead
3. Operator builds up on taper, trailing out the load. Best results are obtained when level grades are not developed until the fill reaches final height.



Typical cut and fill cycle for bulldozer, over maximum operating distance of 90 m

Bulldozer Classification

The table below shows the system for classifying commonly used crawler tractors.

Make	Old Classification	Metric Classification
Cat. D3	4	M5
Cat. D4D	4	M10
Cat. D5	5	M10
Cat. D6B	5	M10
Cat. D7C	6	M15
Cat. D7F	6	M20
Cat. D8H	7	M25
A.C. HD11B	5	M15
Inter. TD9B	4	M7
Case D850	4	M7
Komatsu D85A - 12	6	M20
Komatsu D155A	7	M30
Komatsu D65A-6	6	M15
Komatsu D53A-15	6	M15

Classification of Crawler Tractors

Bulldozer Production Rates

Case Study 7 shows how bulldozer production curves and correction factors are used to calculate bulldozer production rates.

Loaders

By knowing the capacity of the bucket on each available machine, a supervisor can determine which machine is best suited to a job.

Another factor which must be considered is the physical characteristics of the material being loaded. The amount of material carried in the bucket on each machine cycle will not always be the same as the rated capacity of the bucket. The percentage of the rated capacity that is actually retained will vary with each type of material. This percentage is called the Carry Factor. The table below gives typical carry factors for loader buckets.

Material	Factor (%)
Mixed moist aggregates	95–100
Uniform aggregates— up to 3 mm	95–100
— 3 to 9 mm	85–90
— 12 to 20 mm	90–95
— 24 mm and over	85–90
Blasted material— well blasted	80–85
— average	75–80
— poorly blasted	60–65
Moist loam	100–110
Soil, boulders, roots	80–100
Limestone etc	85–95

Table of Carry Factors

The basic calculation for loader production is:

Production per hour = Quantity of material the bucket carries per load x Number of bucket loads per hour

Machine Capacity

The material that a loader moves is either in bank condition or in a loose stockpile.

To adjust the excavated material in the bucket to bank cubic metres, multiply the rated capacity of the bucket by the load factor. For the final machine capacity, this figure has to be multiplied by the carry factor, as follows:

Bank m^3 per cycle = Rated capacity of bucket x Load factor x Carry factor

If the material is in a loose state, determine machine output by multiplying the rated bucket capacity by the carry factor:

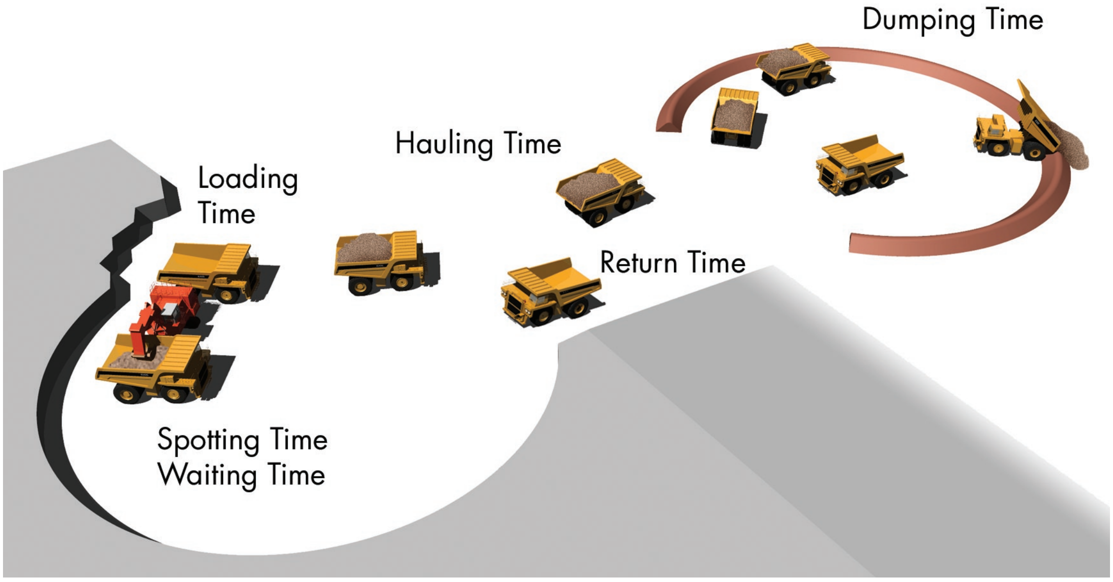
Loose m^3/cycle = Rated capacity of bucket x Carry factor

Trucks

Truck Cycles

The cycle time for a truck consists of six components, as discussed below:

- Loading time, which starts when the loader begins loading the truck, and ends when the truck moves away from the loader.
- Hauling time, which continues until the truck stops at the dump site, and prepares to back onto the dump site.
- Dumping time, which includes turning, backing and dumping the load.
- Returning time, which starts when the truck begins to move away from the dump, and ends when the truck returns to the loading site.
- Spotting time, which is the time required to manoeuvre into position for loading.
- Waiting time, which is the additional time required if the truck has to wait at the loading or dump site.



The drawing shows a typical truck cycle.

Balancing Truck and Loader Capacities

Because the capacity of the loader determines the truck loading time, truck and loader capacities should be balanced. Operating difficulties and higher costs will result if balanced operations are not achieved.

Several factors may affect the output of trucks and the balancing of their capacity with a loader. Size of the trucks is one example.

Comparisons of Larger and Smaller Trucks

The advantages of small trucks over larger ones include:

- They are more flexible in manoeuvring, which may be advantageous on short hauls.
- They have higher speeds.
- Loss of production is reduced when one truck in a fleet breaks down.
- It is easier to balance the number of trucks with the output of the loader.

The disadvantages of small trucks compared with larger ones are:

- It is more difficult for the loader to load the truck body, because of the smaller target area.
- More total time is lost in spotting the trucks because of the larger number involved.
- More drivers are required.
- Since the number of trucks is greater, there is an increased the dangers of 'bunching up' at the pit, along the haul road, or at the dump.

The advantages of large trucks compared with smaller ones are:

- Fewer trucks are required.
- Fewer drivers are required.
- The smaller number of trucks makes it easier to synchronise the equipment and reduces the danger of bunching up.
- They give a larger target for the loader during loading.
- They reduce the frequency of spotting trucks under the loader.

The disadvantages of large trucks compared with smaller ones are:

- The cost of truck time at loading is greater, especially with small loaders.
- The heavier loads may cause more damage to the haul roads.
- It is more difficult to balance the number of trucks with the output of the loader.
- Haulage of larger loads may not be permitted on highways.
- If one large truck breaks down, there will be a larger reduction in output than if a small truck stops.

Loading Trucks to Struck or Heaped Capacity

Another consideration in the operation of trucks is whether to load them to their struck or heaped capacity. Factors influencing this decision are:

- The weight of the material.
- The safe load limit that cannot be exceeded.

- Whether the haul unit is to run on public roads, where legal load limit restrictions apply.
- The maximum safe loads on the tyres. (Overloading could result in considerable lost time due to tyre failure).
- The condition of the haul road. (Overloading could cause a rapid break-up of the surface).
- The power of the engine and the rimpull available to haul the load.

Other Factors Affecting Efficient Truck Management

The following are further considerations in efficient truck management:

- It is desirable to have all trucks of the same capacity and operating at the same speed. This helps to avoid bunching.
- Starting and finishing times of meal breaks should be staggered, as far as possible, to reduce wasted time.
- Separate entrance and exit roads should be provided at the pit.
- The position at which the trucks are to be spotted for loading should be clearly marked.
- Some delay and bunching is inevitable. When selecting the number of trucks on large jobs, add in an additional truck to compensate.

Balancing Truck and Loader Capacities

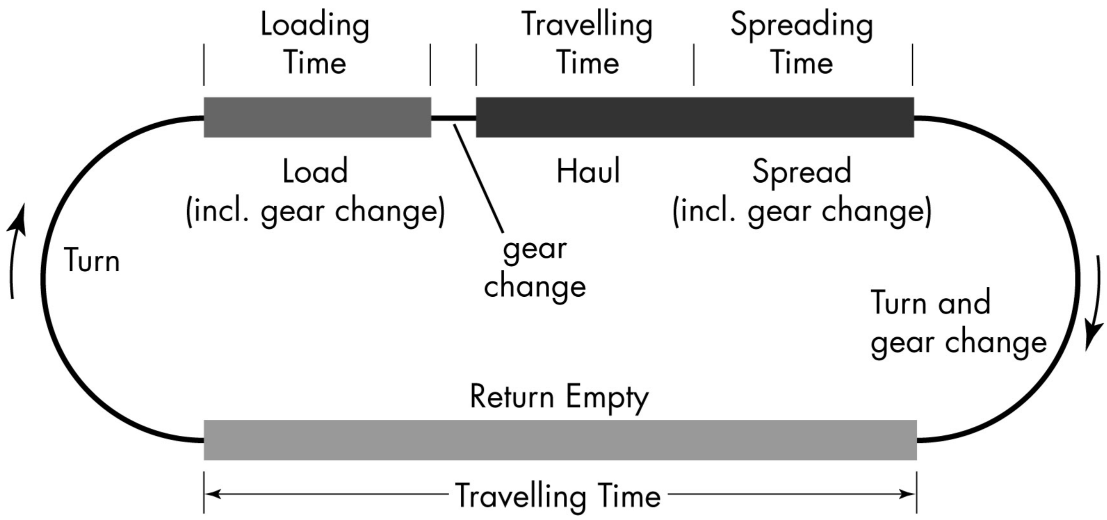
A rule of thumb used in selecting the size of trucks is to use trucks with a capacity of at least four to five times the capacity of the loader bucket.

A trucking operation, or any operation involving the balancing of plant, can become complex. The supervisor must carefully select the number and size of units and supervise their operations closely, to ensure that truck operations are co-ordinated and involve a minimum of lost time.

Scrapers

Scraper Cycles

The cycle of operation of a scraper consists of excavating the load, hauling it to the work site and spreading it, and returning empty to reload, as shown below.

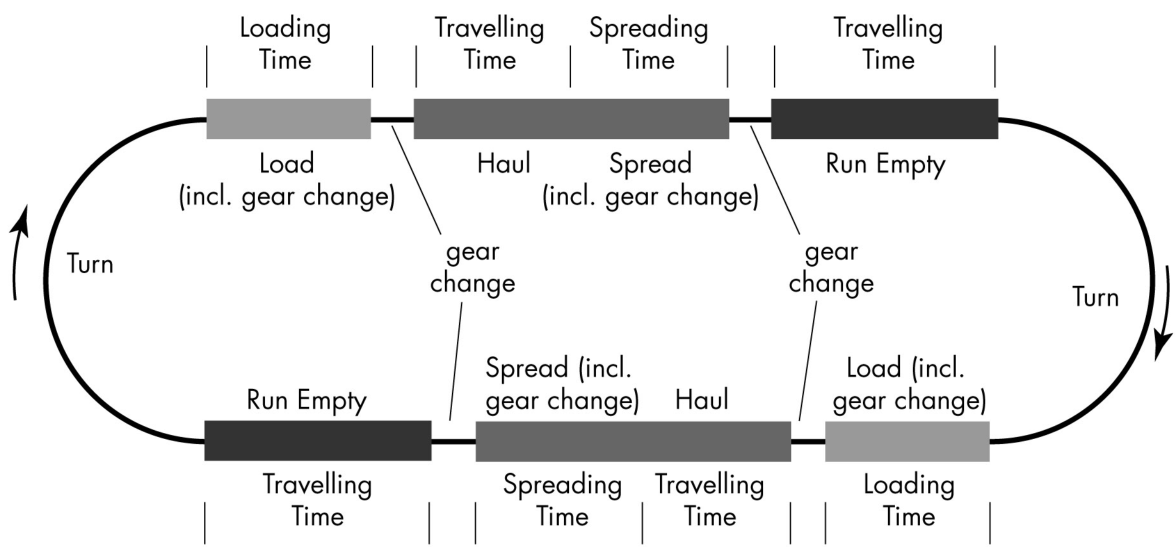


Typical Scraper Cycle

This shows the simplest type of cycle, involving one load, one spread and two turns.

Time taken to accelerate after a gear change is not considered separately as in dozing operations, because it is very short in scraper operations.

Each turn is unproductive time. Therefore, as the number of turns in the cycle decreases in relation to the number of loads hauled and spread, the cycle becomes more efficient.



Efficient Scraper Cycle

The gear changes before loading and before spreading are included in the fixed times for loading and spreading.

The drawing shows a more efficient cycle than the simple scraper cycle on the previous page. In the efficient scraper cycle, the scraper hauls and spreads two loads in a single cycle, involving a total of two turns only.

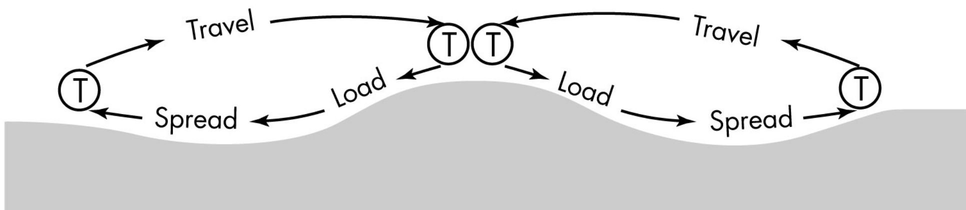
Scraper Circuits

Turns waste time, so you should plan scraper circuits to reduce turns to a minimum. Loaded hauls should be run downhill; if empty hauls have to be uphill, a short climb followed by level or generally downhill running is quicker than a long steady climb.

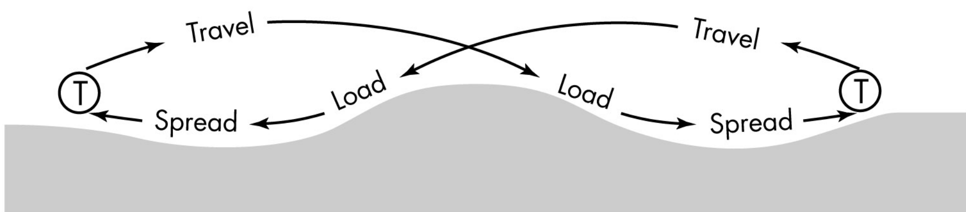
Efficient and less-efficient scraper circuits are shown on the following page, for operations where the scraper is loading from a ridge or hump and spreading in a hollow.

Reduce scraper turns to a minimum

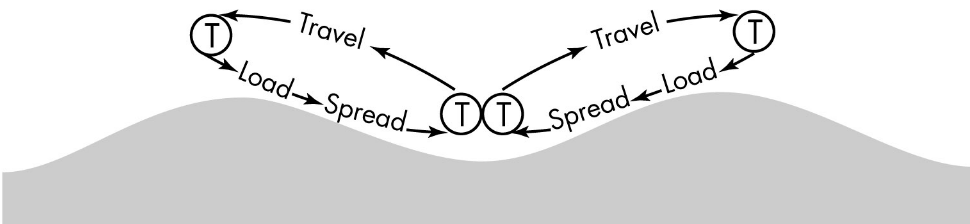
BAD 2 loads, 2 spreads, 4 turns

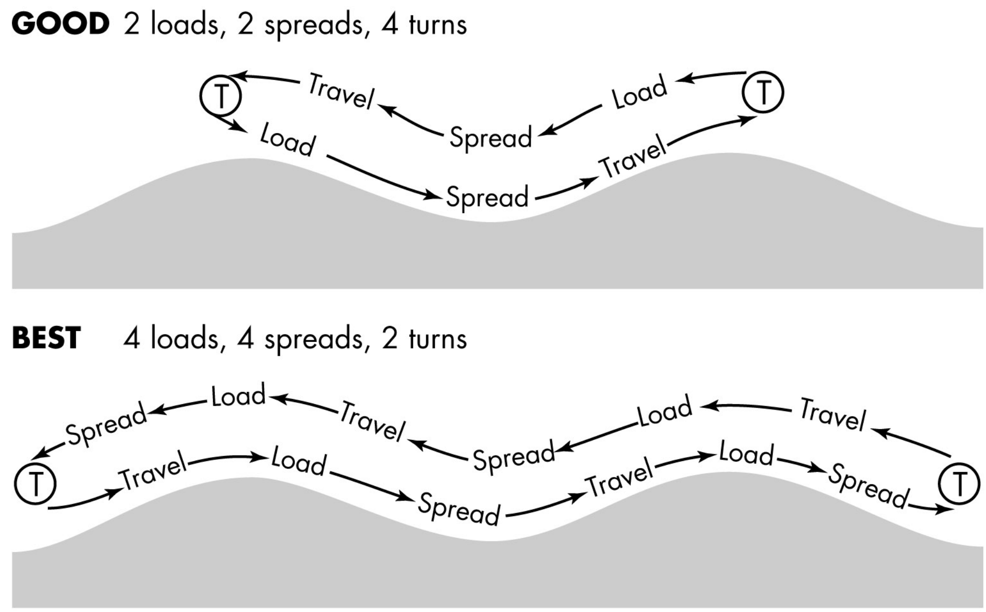


GOOD 2 loads, 2 spreads, 2 turns



BAD 2 loads, 2 spreads, 4 turns



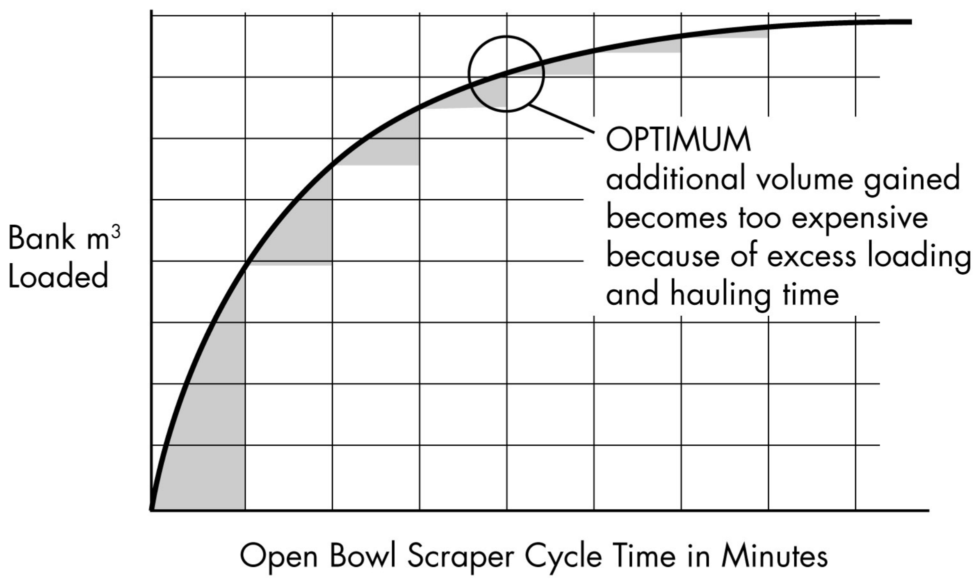


Scraper Operating Patterns

Unless there is plenty of room for safe passing, no scraper can move faster than the one in front of it. Therefore, high-speed wheeled scrapers should (as far as is possible) work separately from those of lower speed, otherwise their principal advantage of speed and quick turning will be wasted.

Scraper Loading

Loading is normally the critical part of the fixed cycle and the scraper should always carry the heaped capacity in cubic metres. However, under actual operating conditions (and with sufficient pusher power), the loose cubic metres carried by the scraper should be between the struck and heaped capacity. The size of the load depends on the type of material being loaded.



Scraper Optimum Cycle Time

Loading to heaped capacity should be completed in:

- 30 metres (or 1 min) for scrapers up to 15m^3 capacity
- 45 metres (or 1½ min) for scrapers over 15 m^3 capacity.

In some soil types, however, the last two or three cubic metres of heaped load may require more time to load than is justified, and a few extra trips may save time. Where this is the case, loads of less than full heaped capacity may be accepted in the interest of output efficiency. The graph above shows this.

Scraper Fixed Time

The following tables of fixed times for scrapers are used to evaluate machine performance.

Element of fixed time	Duration (mins) Size of scraper (heaped) Cubic metres		
	0–10	11–15	16–45
Loading	1.0	1.0	1.5
Each gear change and acceleration to gear speed	0.25	0.50	0.75
Each turn and gear change	0.25	0.25	0.25
Spreading and dumping	0.5	0.5	0.5

Elements of Fixed Time in a Scraper Cycle

Element of fixed time	Duration (mins) Size of scraper (heaped) Cubic metres		
	0–10	11–15	16–45
Loading	1.0	1.0	1.5
Two gear changes and acceleration to gear speed	0.50	1.0	1. 5
Two turns and gear changes	0.50	0.5	0.5
Spreading and dumping	0.50	0.50	0.50
Total fixed time	2.5	3.0	4.00

Total Fixed Time for Typical Scraper Cycles

Machines Operating In Passes

Some machines carry out their work on the soil or road while passing over it. They work back and forth in straight passes.

Machines operating in this manner include:

- Graders
- Rippers and scarifiers
- Ploughs, harrows, rotary hoes
- Mix-in-place stabilising machines
- Compactors
- Bitumen sprayers and pavers.

Work may be carried out on the forward pass only, or on both forward and return passes. It may be completed in a single pass over each piece of ground (single-pass work) or more than one pass (multi-pass work).

Time spent in turning and changing gear between passes is unproductive.

Each pass should be as long as the task and conditions allow, and the operating speed should be as high as is practical.

Comparison of Time Taken for Long and Short Passes

To illustrate this point, consider the operation of a grader over distances of 150m and 1500m respectively. The percentage of time lost is related to the length of each pass and time taken to turn the machine.

$$\text{Time (T) for a single pass of a grader} = \left(\frac{L}{S} \text{ X } \frac{60}{1000}\right) + t$$

Where L = Length of pass (m)

S = Speed of machine (km/h)

t = turning time (min)

In both cases, turning time is 30 secs (i.e. 0.5 min) and operating speed is 5 km/h.

Over 150 m

$$T = \left(\frac{150}{S} \text{ X } \frac{60}{1000}\right) + 0.5 = 2.30 \text{ min}$$

Over 1500 m

$$T = \left(\frac{1500}{S} \text{ X } \frac{60}{1000}\right) + 0.5 = 18.5 \text{ min}$$

Percentage loss in time due to turning for each pass:

Over 150 m: $\frac{0.5}{2.3}$ X 100 = 22%

Over 1500m: $\frac{0.5}{18.5}$ X 100 = 3%

Case Study 8 shows that it is essential to carry out an operation in the longest possible passes that the task and conditions allow.

If the operation requires a machine to stop, turn and reset its equipment, the length of the pass should never be less than 100m.

If the length of the pass is less than 100m, it would generally be less costly to reverse the machine even though the reverse pass is unproductive, as shown in Case Study 9.

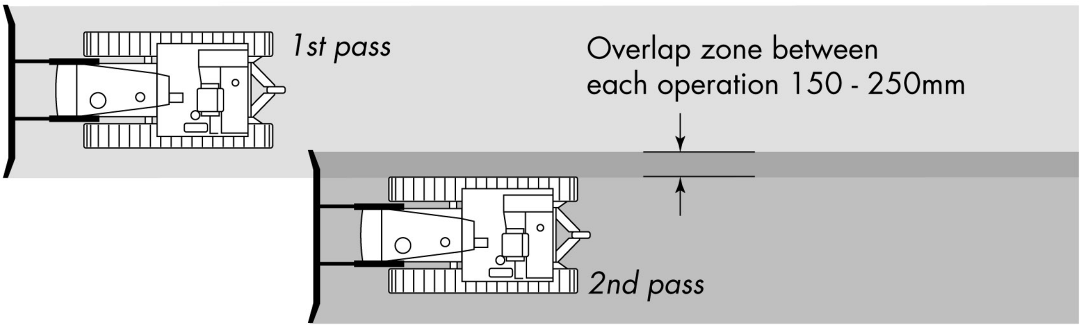
Effective Working Width

The width of the pass can determine the number of passes required to carry out a task or operation. Machines that work in passes may have either a fixed width or a variable width. Fixed-width machines include:

- Bulldozers
- Compaction plant
- Mix-in-place stabilising machine.

Variable-width machines include:

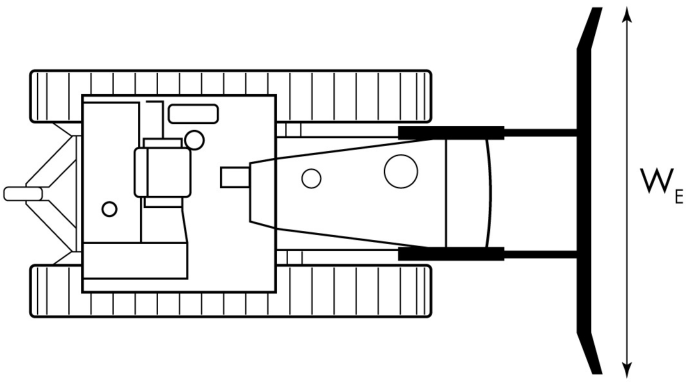
- Angle dozers
- Graders
- Rippers and scarifiers
- Ploughs, harrows and rotary hoes
- Bitumen sprayers and pavers.



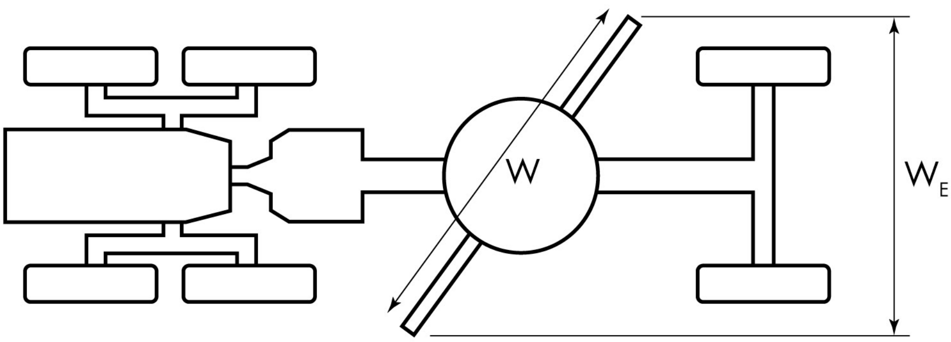
Machines in the fixed-width group are not designed for adjustment of width, e.g. the width of a roller drum cannot be varied. However, in the variable-width group, the effective width of the machine can be altered, e.g. by angling the grader blade or extending the bitumen spray bar.

Because of this, a machine may have both an actual width W and an effective width W_E. The overlap resulting from the difference between actual and effective widths can result in two passes over the same area of ground.

The effective widths of a dozer and a grader are shown in the following illustrations.



Crawler tractor—fixed (W) and effective (W_E) widths of the blade are the same



Grader— fixed length of blade (W) is not the same as effective width (W_E)

Machine Output

The output of machines that work in passes can be estimated in two ways— area of ground treated or volume of soil treated— depending on the nature of the task:

(1) For area of ground treated, we calculate A (area treated, in square metres per hour):

$$A = \frac{1000 \text{ x } S \text{ x } W_E \text{ x } E}{N} \quad m^2/hr$$

(1) For volume of soil treated, we calculate V (volume treated, in cubic metres per hour):

$$V = \frac{S \text{ x } W_E \text{ x } E \text{ x } D \text{ x } F}{N} \quad m^3/hr$$

where:

S	=	Speed of machine (km/h)
W_E	=	Effective width treated (m)
N	=	Number of passes to complete work
D	=	Depth of soil treated in each pass (mm)
E	=	Efficiency factor (assume to be 0.75)
F	=	Soil factor

The effective width W_E is used in both formulas. The terms D (for depth) and F (for soil factor), however, appear only where output is measured as volume treated.

Graders

A grader plays important roles on construction sites by maintaining roads and finishing final grades. While the grader's rate of production is subject to many variables, two— operator efficiency and the material being worked— are more important than for other machines:

We measure grader production in terms of area covered rather than cubic metres moved. The person supervising the grader operation is therefore interested in the time required to complete a job.

The most important piece of information needed to work out the required time is the number of passes needed to complete the job. With each successive pass, the material becomes easier to work, allowing faster travel speeds. Therefore, not all passes will be at the same speed.

This is taken into account when calculating the time taken to complete grader work.

Compactors

One cubic metre of material that has been compacted, and has shrunk as a result, is called a 'compacted cubic metre'. Compactor production is expressed in compacted cubic metres per hour.

Fill material must be compacted to provide a stable base for subsequent construction. Usually, the engineer gives the specifications for compacting to the supervisor on the job. By knowing the compacted depth of the material and the number of passes required, the supervisor can estimate compactor production.

The number of passes depends mainly on the type of material being compacted and its moisture content. For an earthworks job, the supervisor works out the number of passes by observation and test rolling a section at the start of the job. For rock fills, the number of passes and type of roller will be specified.

The volume that a machine can compact in a 60-minute hour is calculated from the formula for volume of soil treated:

$$V = \frac{S \times W_E \times E \times D \times F}{N} \ m^3/hr$$

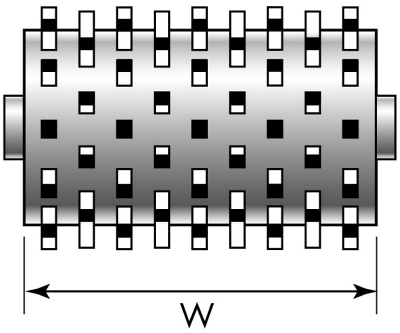
The required volume of excavation in bank cubic metres to complete the fill can be estimated by allowing for shrinkage.

When estimating production according to the formula, use the following average speeds as guidelines when actual speed measurements are not available:

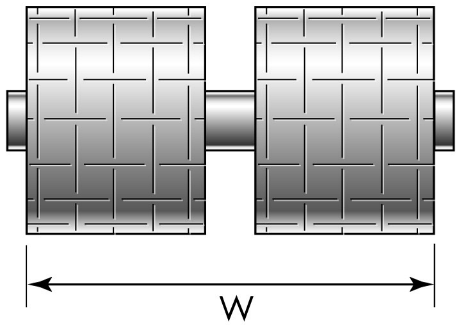
Type of roller	Average speed
Self-propelled sheepsfoot	8.0 km/h
Self-propelled tamping foot	10.0 km/h
Self-propelled pneumatic	11.0 km/h
Sheepsfoot and tamping rollers towed by a wheel tractor	8.0–16.0 km/h
Sheepsfoot and tamping rollers towed by track-type tractor	5.0–7.0 km/h
Towed pneumatic rollers	5.0–8.0 km/h
Grid rollers towed by wheel tractor	20.0 km/h

Fixed widths of some of these types of rollers are shown in the following illustrations.

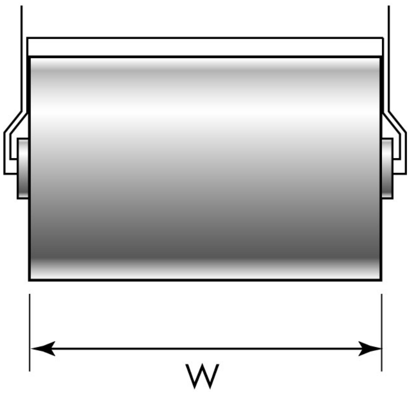
Tamping Foot or Sheep's Foot Roller



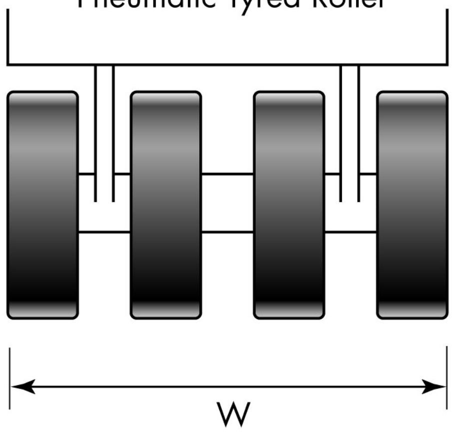
Grid Roller



Steel Wheel Roller



Pneumatic Tyred Roller



The equipment manufacturer provides tables that may be used to estimate compactor production.

Power Required for Towed Compactors

Where a compactor is towed, the power required to pull it is affected by the type of compactor and soil, the soil moisture content, and the grade.

Rolling resistance for a sheepsfoot roller is approximately 250 kg/tonne of weight for 150 mm compacted lifts of average material.

Rolling resistance for tamping-foot compactors varies greatly with foot design and ground pressure, but generally is less than that of a sheepsfoot compactor.

Pneumatic Tyred Compactors

To estimate rolling resistance, add 5 kg/tonne for each 25 mm of compacted depth of lift to the rolling resistance factors (i.e. those shown in the table of rolling resistances of wheeled vehicles).

The rolling diameter of the compactor drum is important in determining power required. For a given weight, smaller rolling diameters require greater drawbar pull.

As the loose layers under a roller tighten up, the power required will decrease (i.e. as rolling resistance decreases), and travel speed will therefore increase.

General Comment on Determining Plant Requirements

Because of different conditions and the number of plant items available to do the same job, there is no simple set of standards for calculation of machine outputs.

The only way to tackle problems caused by changing plant and conditions is to estimate the outputs by the cycle-time method, and then verify the assumptions you have made by arranging actual field observations and recording the plant's performance.

Supervisors must be briefed about the tasks, expected outputs and cycle times of plant being used on the job. If this briefing is overlooked, the actual operations may turn out to be radically different to the planned arrangement.

Theoretical planning of plant requirements before the job gets under way is often optimistic. Some people tend to over-stock the site with plant. Once an item is on site, they may feel reluctant to dispose of it. Inefficiency and cost over-runs are the inevitable results.

When corrective action is needed, do not hesitate or delay. You are well advised to take a critical view of plant activity at all times.

Determine Equipment Requirements

The following discussion refers to large static equipment and to miscellaneous smaller equipment that may be used on a construction job.

Static Equipment

The cycle of operations of scrapers, dozers, loaders and trucks is readily recognisable. Other machines (e.g. Airtrac drills) also have a cycle of operations, through it may not be so obvious.

These machines are moved to a site, are positioned (or set up), carry out their function and then move (or are moved) to another site where the cycle commences again.

In this instance, the travelling and setting-up time is non-productive and the machines do not return to their original site.

Miscellaneous Equipment

A wide variety of small, powered equipment is available for use in construction work. Examples include:

- wackapackas
- bobcats
- dingos
- mini-excavators
- welders
- generating sets
- lighting plant
- chainsaws
- scissor lifts
- concrete finishers ('helicopters').

The job may include sufficient work to justify the use of one or more of these machines. If so, the rates of production of these items of equipment must be considered, as for other equipment.

Appropriate measures may include:

- cubic metres excavated per hour
- cubic metres treated per hour
- square metres compacted per hour
- cost per kWh of electricity generated.

Determine Labour Requirements

Efficiency of Labour

The basis of estimating labour efficiency was discussed in a previous section. It is expressed as a percentage, equivalent to the number of minutes per hour that the people on the job are working at full efficiency (e.g. 45 minutes of efficient work per working hour is 75% efficiency).

As the person responsible for the productivity of the work group or of several work groups, you should be constantly assessing this percentage. There may be many reasons why this factor can change over time, e.g. it may fall after a long period of demanding work, or if interpersonal factors change working relationships within the workgroup.

If labour efficiency is constantly down and you have issued appropriate warnings, you will need to decide on appropriate corrective action. The exact nature of this action will depend on your knowledge of the people involved, the guidelines for hiring, firing and disciplinary action, and the nature of the job.

Consideration of Skills

Before the job begins, the supervisor must assess the availability of skilled personnel for the job, and (wherever possible) match these to the skill requirements of each activity that forms part of the job. Generally, people with a certificate qualification in one or more construction skills would be preferred.

Crew Size

As a leading hand, foreman or supervisor, you will (at some time) face the question: 'What is the best number of people to put together in a work crew?'

The answer depends on:

- the type of work being performed
- the scale of the job
- behavioural factors.

Effect of Type of Work

With some types of work, the number of people is straightforward. For example, if a road is being built on a new alignment, the work involved would include clearing trees and bushes, sorting saleable timber and pushing other material into heaps for burning. (However, burning of the material will depend on environmental considerations). This work would normally require a dozer operator and an assistant.

Similarly, if the sub-grade of the new road has to be rolled, the labour requirement will be one roller operator.

In many other cases, however, there are more options and the leading hand, foreman or supervisor will need to decide how many people to put together in a workgroup.

Effect of Scale

Where the job is of a very large scale, e.g. widening a section of highway 15 km long, the job will need an organisational structure. For example, on a large road job, there may be:

- an earthworks and a drainage work group, each with a leading or foreman in charge, with both workgroups reporting to an earthworks foreman
- a quarry and a pavement work group, each with a leading or foreman in charge, with both workgroups reporting to a roadworks foreman
- a works supervisor in charge of the overall operation.

The various types of workplace organisation were discussed in Section 1, Planning the Work. This showed that the number of people per crew will depend partly on how the job is organised; for example, how many earthworks, drainage or roadwork gangs there are.

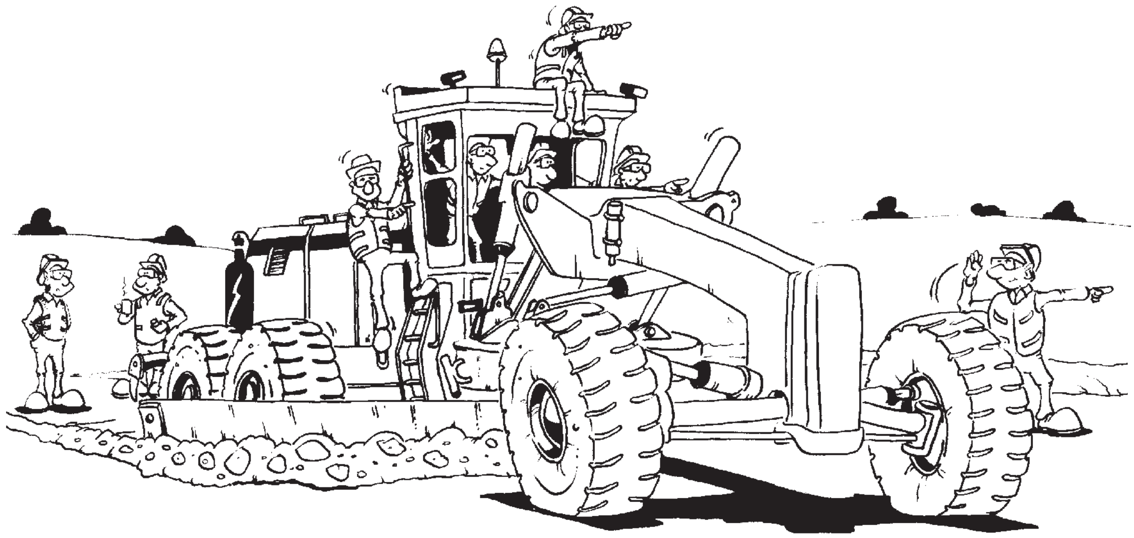
Behavioural Factors

How large should a work group be? Behavioural scientists have conducted many case studies in industry over an extended period, in an attempt to answer this question. There appears to be a general relationship between the productivity of each person in a workgroup and the number of people in the workgroup, and this can be plotted as a graph. While the actual shape of the graph varies with site and labour conditions, the general form of the relationship is as shown below:

Change in Labour Productivity

The trend is for the average output of each person in the group to increase initially as the size of the workgroup increases, and then decrease.

As workgroups become larger, people tend to use up more time in establishing and maintaining working relationships with others, and less time actually working. The reason for this is simply that there are more opportunities to interact with other people.



Some studies have led to the conclusion that the best size for a group of outdoor workers is 5–6 people. However, there is no fixed or 'magic' number. In all cases, you need to take the needs of the job into account, and to watch how the group is actually performing on the job.

While the best size for a works crew depends on many factors, the size of the group should not be so large that interpersonal factors reduce the group's output.

Determine Materials Requirements

In construction work, materials such as concrete, gravel, sand, water, wood, and steel are commonly used. Determining materials requirements on the job usually means:

- making measurements with a measuring tape
- recording the measurements
- performing simple calculations.

The main types of calculation that we need to make on a regular basis are for area and volume. The following paragraphs explain the various types of area and volume calculations commonly used in construction work, and show how the calculations are performed.

Calculating Areas

The three most common area calculations are for rectangle, square and circle.

Rectangle

A rectangle is a flat surface where one side (the length) is longer than the other (the width). The area of a flat, rectangular surface is calculated as Length x Width. Both length and width must be expressed in the same units, usually millimetres or metres. Area is expressed in square millimetres (for very small areas) or (more commonly) in square metres.

For example, an area of road 1500 m long by 8 m wide is to be covered with a mixture of gravel, binder and water. The total area is:

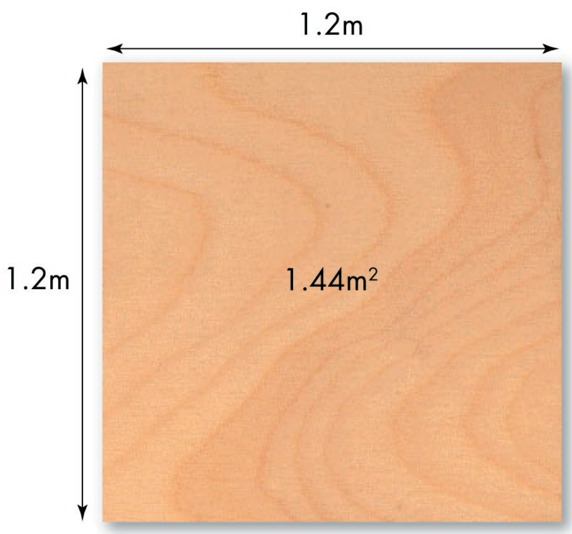
1500 x 8 = 12000 square metres.

Examples of calculations involving rectangles, and rectangles within rectangles, are shown in Case Studies 11 and 12.

Square

A square is a special case of a rectangular area, in which the length and width are the same. The area of a square can therefore be calculated as Length x Length, or Length squared. For example, a square piece of plywood with a side of 1200mm (= 1.2m) has an area of:

1.2 x 1.2m = 1.44 square metres.

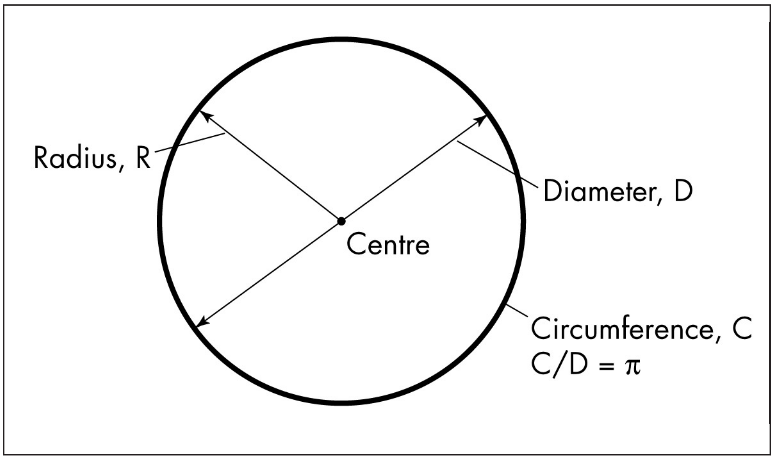


Rather than write 'square metres' every time we want to state an area, we can use either of the following abbreviations:

- m^2
- sq m.

Circle

The area of a circle is frequently used in construction work.



A circle is a regular shape in which all points on the outer edge (or perimeter) are the same distance from the centre. The distance across a circle is called the diameter; the distance from the centre to the perimeter is the radius. The circumference is the distance around the perimeter of the circle.

In all circles, the ratio of the circumference to the diameter is a unique number called Pi (Greek symbol π). Pi is approximately equal to 3.14 159 265 358 979…. For practical purposes, we use $\pi = 3.1416$.

To calculate the area of a circle, we use either of two formulas:

$$\text{Area} = \pi R^2$$

$$\text{Area} = \frac{\pi D^2}{4}$$

An example of a calculation involving circles is shown in Case Study 12.

Calculating Volumes

'Volume' means the amount of space occupied by a three-dimensional object. The space may be a solid object (such as a block of concrete) or an empty space (usually referred to as a void). Two main types of volume calculation are needed for construction work.

- rectangular and cubic spaces
- cylindrical spaces.

An example of volume calculation for a cylindrical space is shown in Case Study 15.

Volumes of Rectangular and Cubic Spaces

The volume of a rectangularly shaped space is calculated as Length x Width x Depth. Length, width and depth must be expressed in the same units, usually millimetres or metres. Volume may be expressed in cubic millimetres or cubic centimetres (for small spaces) or, more commonly, in cubic metres.

A cube is a special case of a rectangular space, in which the length, width and depth are the same. The volume of a cube can therefore be calculated as Length x Length x Length, or Length cubed. For example, a cubic block of wood with a side of 100mm (= 0.1m) has a volume of:

0.1 x 0.1 x 0.1 = 0.001 cubic metres.

Rather than write 'cubic metres' every time we want to express a volume, we can use either of the following abbreviations:

- m^3
- cu m.

Examples of volume calculation for rectangular spaces are shown in Case Studies 13 and 14.

Relationship between Fluid and Solid Cubic Measures

There are two types of cubic measure in the metric system, as used in Australia. 'Litres' (symbol L) are used for the volumes of fluids, while cubic metres (etc.) are generally used for solids. A litre is made up of 1000 mL (millilitres), and each millilitre is almost exactly the same as 1 cubic centimetre. As one centimetre is $1/100^{th}$ of a metre, a cubic metre is made up of:

100 x 100 x 100 = 1 000 000 cm^3 (cubic centimetres)

However, this is the same as 1 000 000 millilitres. One thousand millilitres make one litre. Therefore—

1 m^3 = 1 000 000/1000 = 1000 litres.

However, when we are dealing with large quantities of water or other fluids, we can use either type of measure, as convenient. For example:

- the volume of water delivered in a road-watering truck may be expressed in kilolitres (thousands of litres) or cubic metres (1kL = 1 m^3)
- the volume of water held in a dam may be expressed in megalitres (millions of litres), or in cubic metres (1ML = 1000 m^3).

Formulas Used to Calculate Areas and Volumes

The following table shows formulas commonly used in the construction industry to determine materials requirements.

Type of Calculation	Type of Figure	Formula	Alternative Formula
Area	Rectangle	Length x Width (L x W)	—
	Square	Length x Length (L x L)	Length squared (L^2)
	Circle	πR^2	$\frac{\pi D^2}{4}$
Volume	Rectangular shape	Length x Width x Depth (L x W x D)	—
	Cube	Length x Length x Length (L x W x L)	Length cubed (L^3)
	Cylinder	πR^2 x Length	$\frac{\pi D^2}{4}$ x Length

Calculating Cycle Times and Rates of Production

The following discussion and examples show how cycle times and/or rates of production may be calculated for a number of plant items:

- bulldozers
- loaders
- trucks
- scrapers
- machines that work in passes (graders, rollers and compactors)
- static equipment.

The considerations and calculations used here are the starting point for the overall process of determining how long the job will take. (See sections 3, 4, and 5 in this module).

Bulldozer

The calculations for a dozer involve the following steps:

- Collect basic information
- Check that drawbar pull will be adequate
- Calculate cycle time
- Calculate production rate:
  - uncorrected
  - corrected.

Basic Information for Dozer

The basic information needed for calculating dozer cycle time and production includes:

- class of dozer (e.g. M25)
- tracked or wheeled
- S or U blade
- tilt or fixed blade
- blade capacity in m3 (either calculated from a formula or read from manufacturer's manual)
- type of material being shifted, density and load factor
- tractive efficiency of the machine while working in the material
- distance over which material is shifted
- grade and whether uphill, level or downhill dozing
- dozing technique (eg. slot dozing).

Drawbar Pull

The dozer's blade capacity in m3 is either calculated from a formula or read from the manufacturer's manual. This figure is multiplied by the density of the material (obtained from the Table of Material Properties) to give a blade capacity in kg.

From past experience, the gear in which the machine will work best in the conditions (e.g. in a borrow pit) will be known.

The adequacy of the machine's drawbar pull is then checked by comparing the weight of material in a blade load against the drawbar pull that the machine can exert in the selected gear.

Calculate Cycle Time

The dozer cycle consists of fixed time and travel time.

Fixed Time

Total fixed time for forward and reverse movement consists of two gear changes and the maximum fixed time taken to shift into gear and accelerate to gear speed is known. The actual amount depends on whether it is a power-shift or non-power-shift machine. It may be possible to reduce the figure if the operator is experienced and proficient.

Note!
The machine would have to be timed while actually performing the operation, to obtain accurate fixed times.

Travel Time

To calculate the travelling time for each gear speed, use the formula:

$$\frac{\text{Haul distance – distance travelled in the fixed time}}{\text{Gear speed}}$$

The lead distance is known (e.g. 50 m), and the distance travelled in the fixed time is obtained from a graph of distance travelled at different speeds.

This calculation is done separately for forward and reverse travel; the speed in reverse will be slower for the same gear. For example, from the table of speeds in gears for a particular machine, we can find that the forward speed is 4.0 km/h and the reverse speed is 4.8 km/h in 2nd gear.

To calculate time spent travelling forward, we take away the distance travelled in the fixed time (in this case, at 4.0 km/h) from the lead or haul distance, divide by the distance travelled in one hour at 4.0 km/h, and multiply by 60 minutes.

To calculate time spent travelling in reverse, we take away the distance travelled in the fixed time (in this case, at 4.8 km/h) from the lead distance, divide by the distance travelled in one hour at 4.8 km/h, and multiply by 60 minutes.

The total travelling time is the sum of the times spent in forward and reverse.

Total Cycle Time Calculation

The total cycle time is the sum of the travelling time and the fixed time, as calculated earlier. Both times will be in minutes.

Calculate Production Rate

The machine production rate is first calculated as an uncorrected figure. This, in turn, is multiplied by correction factors.

Calculate Uncorrected Production

To find the uncorrected production, read the figure in cubic metres per hour (m3/h) from the relevant production curve for the specified conditions. Examples of production curves and the conditions attached to them are shown in Case Study 8. For example, reference to the curve for a Class M25 (D8) dozer pushing over 50m shows that it produces 400 loose m3/h with an S blade.

The production curves are available from the manufacturer's handbook for the machine. The figure is uncorrected maximum production.

Calculate Corrected Production

The uncorrected maximum production read from the production curves is based on the assumptions specified in the footnotes to the curve. It has to be corrected to allow for:

- soil density (e.g. if the material is heavier, the production rate will be less)
- operator efficiency (in minutes per hour or percent)
- use of tilt cylinder (e.g. hard to cut material means more effort and reduced efficiency)
- dozing technique (e.g. slot dozing increases production above uncorrected)
- task efficiency (usually 1.0 for dozers)
- correction for grade (greater then 1.0 if downhill).

The method of correction consists of two steps:

- read the relevant correction factor in each case (soil density, operator efficiency, etc) from tables
- multiply the uncorrected maximum production (as read from the production curves for the machine) by all the factors.

This calculation usually yields a production figure that is much less than that obtained from the estimated production curves. If you do not apply the various correction factors, you will overestimate the production rate. In addition, the correction factor to convert from loose to bank cubic metres must be used.

Alternatively, to calculate the machine's corrected production rate, the following formula may be used:

$$\text{Output} = \frac{Q \times F \times E \times 60}{Cm} \; m^3 \text{ (bank)/h}$$

, where

- Q is the quantity in a blade load in cubic metres
- F is the soil factor (i.e. correction for bank cubic metres)
- E is task efficiency (normally 1.0 for major-role machines)
- C_m is cycle time in minutes.

The final figure obtained from the formula is in bank cubic metres per hour.

Calculating Loader Cycle Times

A loader cycle consists of load, haul, dump and return. Different calculations apply to tracked and wheel-type loaders.

Track-Type Loader

Load Time

Load time will depend on the type of material. The time taken to load a particular type of material can usually be read from a table. An example is shown below.

Material	Minutes
Uniform aggregates	0.03–0.05
Moist mixed aggregates	0.04–0.06
Moist loam	0.05–0.07
Soil, boulders, roots	0.05–0.20
Limestone etc.	0.10–0.20

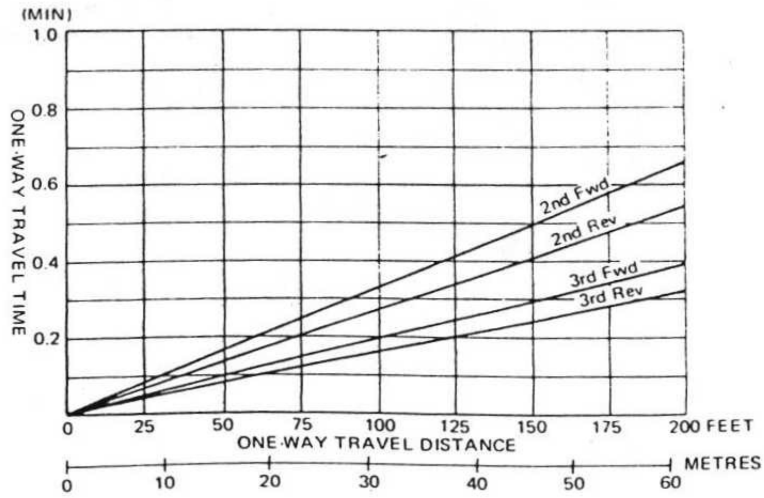
Table of Load Times for a Track Type Loader

Dump Time

Dump time is dictated by the size of the dump target and varies up to 0.10 of a minute. Typical dump times into highway trucks are from 0.04 to 0.07 of minute.

Haul and Return Times

Haul and return times can be determined by using a travel graph. A typical travel-time estimation graph is shown below. When estimating cycle times for a machine, always check that you are using the graph applicable to that machine.



Travel Time Estimating Graph

Use of the Travel-Time Estimation Graph

The travel-time estimation graph shown above applies under the following conditions:

- There are no grades.
- There is no practical difference between the loader's loaded and empty speeds.
- Bucket position stays unchanged during travel.
- Travel in manoeuvre time is not included.
- Acceleration time is accounted for as manoeuvre time.

The travel-time estimation graph is not used when the loader is simply loading, turning, and dumping into a target next to it— in other words, there is no load and carry operation. In this situation, the time elapsed between load and dump (manoeuvre time) will be about 0.22 minutes at full throttle with a competent operator.

Wheel-Type Loader

Basic Cycle Times

The cycle time of a wheel loader is made up of the same four parts: load, haul, dump and return. However, to make problem-solving easier, it can be looked at in another way.

The basic cycle time for a fixed frame loader is 0.5 minutes. For an articulated loader, it is 0.4 minutes. These are averages and variations may occur. The basic cycle includes loading, dumping, manoeuvring and minimum travel.

Cycle-Time Corrections

The table of cycle time corrections for wheel-type loaders (see below) gives corrections to the basic loader cycle time. This is based on normal loader operating conditions, including:

- stockpiled material, broken to granular
- haul areas sufficiently hard and smooth to use full throttle while travelling
- a competent operator
- unit properly equipped for job conditions
- loading into hoppers or trucks matched to the loader.

Add the applicable numbers in the table to, or subtract them from, the basic cycle times of 0.5 or 0.4 minutes.

Materials	Minutes added to (+) or subtracted from (–) basic cycle time
Mixed	+0.02
Up to 3 mm	+0.02
3 mm to 20 mm	–0.02
20 mm to 150 mm	0.00
150 mm and over	+0.03 and up
Bank or broken	+0.04 and up
Pile	
Conveyor or Dozer piled 3.00 m and up	0.00
Conveyor or Dozer piled 3.00 m or less	+0.01
Dumped by truck	+0.02
Miscellaneous	
Common ownership of trucks and loaders	Up to –0.04
Independently owned trucks	Up to +0.04
Constant operation	Up to –0.04
Inconsistent operation	Up to +0.04
Small target	Up to +0.04
Fragile target	Up to +0.05

The last thing to consider on cycle time is the distance the material is carried. If it is minimal, there is no need to change the basic cycle time.

For longer distances, applicable travel-time graphs for wheel loaders are used. Times read from the graphs are added to the basic cycle time. The graphs generally do not show a 3rd-gear curve, because this gear is primarily used for transporting the machine.

To calculate the cycle time, add times taken to manoeuvre the loader, load and dump, to the travel time.

Note!
Always check that you are using the specific graph applicable to the machine.

Truck Cycle Times

A truck cycle consists of six components:

- excavator loading time
- haul and return times
- dumping time
- spotting time
- waiting time.

The effect of each on the cycle time is described below.

Excavator Loading Time

Loading time depends on the capacity of the loader being used. To find load time, calculate the number of full passes required to load the truck to its rated capacity. Partial bucket loads are not considered in this calculation.

Truck manufacturers produce charts that enable matching truck type to excavator type, by showing the numbers of full passes required to load a truck to its rated capacity with a particular excavator.

Haul and Return Times

Estimate haul and return times by using the manufacturer's table of maximum speed in gears, and tables such as that shown below.

Length of haul (metres)	Short, level hauls of 150 to 300 m (total length)	Truck starting from scratch	Truck in motion when entering haul road section
0–100	0.20	0.25–0.50	0.20–0.50
100–250	0.30	0.35–0.60	0.60–0.75
250–450	0.40	0.50–0.65	0.70–0.80
450–750	—	0.60–0.70	0.75–0.80
750–1000	—	0.65–0.75	0.80–0.85
1000 and above	—	0.70–0.85	0.80–0.90

Factors for Conversion of Maximum Gear Speed to Average Speed

To determine the average actual travel speed, multiply the maximum gear speed by the factor opposite the length of haul road section concerned. Next, calculate the time using the average speed and the length of the haul road.

Dumping Times

Read dumping times from the table below, when the type of truck is known.

Type of truck	Time taken in cycle operation (minutes)
Rear tipping, less than $7m^3$	1.0
Rear tipping, more than $7\ m^3$	1.5
Bottom dump semi-trailer	0.5–0.75

Table of Approximate Times for Trucks to Discharge Loads and Turn (under average conditions)

Spotting Time

Truck spotting time is usually taken as a maximum of 0.5 minute.

Waiting Time

Waiting time is the total time spent by a truck waiting to either load or unload. Each of these times must be measured while the truck is in operation.

Calculating Truck Cycle Times

The method of calculating truck cycle times is to add the five components, as shown in the table below.

Component	Source of information	Component identification
Excavator loading time	Time to load–haul–dump–return (if crawler-mounted loader) OR Corrected cycle time plus travel time (if wheel loader)	= A
Truck haul and return time	Table for conversion of maximum speed in gear to average speed	= B
Dump	Table of times required by trucks to discharge load and turn	= C
Spotting	0.5 minutes	= D
Waiting time	As measured by stop-watch on-site	= E
Truck Cycle Time = A + B + C + D + E		

Scraper Cycle Time and Production

The sequence of calculations used to determine scraper output is:

- collect scraper, haul road and material data
- calculate cycle time
- calculate output.

The calculated output result is then used to determine the requirement for scrapers on the job.

Collect Data for Scraper, Haul Road and Material

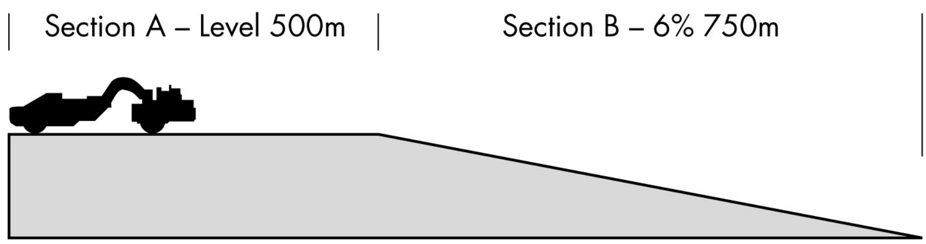
Scraper Data

The relevant data is extracted from the manufacturer's manual for the specific machine. The following data is usually required:

- Heaped capacity of scraper in m^3
- Top speed in km/h
- Weight on wheels, empty, of tractor and scraper (kg)
- Weight on wheels, loaded, of tractor and scraper (based on a specified average load size) (kg)
- Per cent of weight on the drive and scraper wheels, loaded.

Haul Road Data

The average gradients are expressed as percentages of the total one-way haul distance, as shown in the example below, where the total haul is 500m + 750m = 1250m.



Material Data

The weight of the material in kg/m^3 comes from the table of material properties. The adopted figure is for kg per loose m^3.

Cycle Time

The normal cycle of operations for a scraper is:

- load
- travel to tip site
- spread material
- return.

Calculating the length of this cycle involves a total of five calculations:

- calculate fixed time
- calculate travel time, loaded
- calculate travel time, unloaded
- calculate total travel time (i.e. combine loaded and unloaded)
- combine fixed time and total travel time to obtain cycle time.

Some of the details of the calculations for fixed and travel times are shown below.

Calculate Fixed Time

The total fixed time for the operation is read from the table of Total Fixed Time for Typical Scraper Cycles (see page 35). The figure comes from reading down the column for size of scraper (heaped) in cubic metres.

Calculate Travel Time

The travel time depends on the speed at which the scraper will operate. There are two ways of working out the speed: we can either record the time of an average scraper cycle using the stopwatch, or to calculate it. The calculations are beyond the scope of this training, but (briefly) they involve:

- Using total weight of tractor and loaded scraper to find load acting on driving wheels
- Calculating maximum usable rimpull and checking it against total required rimpull
- Using rimpull curve to calculate maximum speed in selected gear
- Using speed to calculate travel time loaded on grade and level sections
- Combining times on grade and level sections to obtain travel time, loaded
- Repeating the calculations for grade and level sections to obtain travel time, unloaded (i.e. for empty return haul)
- Calculating total travel time in minutes by adding four figures:
  - time taken loaded on level section
  - time taken loaded on graded section
  - time taken empty on level section
  - time taken empty on graded section.

Calculating Machine Output

The machine's output is calculated from the formula:

$$\text{Output} = \frac{Q \times F \times E \times 60}{Cm} \text{ (bank) m}^3/\text{h}$$

where Q = Quantity of material being carried, in this case heaped capacity of the scraper (m3)

F = Soil factor, obtained from the table of material properties, or from field data

E = Combined efficiency factor

= Task efficiency factor [1.0 for a scraper] x Operator efficiency factor

C_m = Cycle time, as calculated above.

The machine output figure is then used to determine the job plant requirement. The final output figure is then applied directly to the total quantity of earth to be shifted. For example:

If the output was 37.6 m3 (bank) per hour and the job required shifting of 10 000 bank m3, the machine would take:

$$\frac{10000}{37.6} = 266 hours$$

If the operators are working 40-hour weeks, the machine would be working on site for:

266/40 = 6.65 weeks

Effectively, this would mean booking one machine for seven weeks.

Similar calculations can be used for other plant and equipment items, to determine the length of time for which they are required on a works site.

Machines That Work in Passes

Production rates for machines that work in passes are determined in either square metres per hour (e.g. for graders or rollers) or cubic metres per hour (e.g. for compactors).

Grader Cycle Time

The following example shows how grader cycle times are calculated.

To maintain a haul road, a grader makes one pass in 2nd gear and then two passes in 3rd gear. The machine speeds are 6.0 km/h in 2nd and 9.2 km/h in 3rd, and it averages 50 productive minutes per hour. How long will it take to complete the job if the haul road is 8.5 kilometres long?

Using a task efficiency factor of 1 for a grader operating in passes greater than 600m (from the table of task efficiency factors) and an operator efficiency factor of 0.83 (figure for a good operator), the calculation of combined efficiency factor is:

Combined efficiency = 1.0 x 0.83 = 0.83

Length of road: 8.5 kilometres

Therefore the time taken to cover each pass is:

Pass Number	Gear	Speed	Time Required
1	2nd	6.0 km/h	$\frac{8.5\text{ km}}{6.0\text{ km/h}} = 1.42\text{ hrs}$
2	3rd	9.2 km/h	$\frac{8.5\text{ km}}{9.2\text{ km/h}} = 0.92\text{ hrs}$
3	3rd	9.2 km/h	$\frac{8.5\text{ km}}{9.2\text{ km/h}} = 0.92\text{ hrs}$
			TOTAL = 3.26 hrs

The total time is then adjusted to allow for the combined efficiency factor. The time taken at 83% efficiency, as calculated above, is:

$$= \frac{100}{83} x\ 3.26$$
$$= 3.93 \quad hours$$

Roller Production in Square Metres per Hour

The following examples show how to calculate:

- roller production rate in m^2 per hour
- time required to cover a specified area.

Roller Production Rate

Determine the output of a steel-wheel roller which has a roller width of 2.1m. From compaction trials, it has been found that the roller will achieve the specified density in 5 passes travelling at 6 km/h. The formation width is 7.8 m.

The effective width of the roller is the width of the roll minus the overlap width between the two operations. Because overlaps are generally between 150 and 250mm wide, we assume an overlap of 150 mm:

$$\text{Effective width WE} = 2.1\text{m} - 150\text{mm}$$
$$= 2100 - 150 \text{ mm}$$
$$= 1950 \text{ mm, i.e. } 1.95 \text{ m}$$

Using the formula for area of ground treated per hour, the rate of coverage is:

$$\text{Area} = \frac{1000 \times 6 \times 1.95 \times 0.75}{5}$$

$$= 1755 \text{ m}^2 \text{ per hour.}$$

Time to Cover Specified Area

Toc calculate the time it would take for the roller to compact the full formation width of a section of the road 100m in length is found from area to be compacted (formation width by length = 100m x 7.8m = 780m2) divided by production rate per hour.

$$\text{Time taken} = \frac{780}{1755} = 0.44 \text{ hrs.} = 27 \text{ minutes}$$

Compactor Production in Cubic Metres per Hour

Compactor production rate is read directly in compacted cubic metres from the compactor manufacturer's production table. The following information must be known about the compactor:

- speed at which compactor is travelling
- number of passes made over the material
- type of material
- thickness of material to be compacted (also known as the 'lift').

Static Equipment Cycle Time

The method of calculating the cycle time of an item of static equipment is to break down the machine's operation into steps, and decide which steps have a fixed time, and which are variable.

Obtain information for fixed times from the manufacturer's manual for the machine, if possible. Time operations in the field directly to obtain information on variable times.

The cycle of operations for a drill rig used in rock blasting might consist of the following:

Step no.	Fixed (F) or Variable (V) time	Operation
1	F	Move to marked drill position
2	F	Adjust boom and drill support frame to bring drill stem into correct position and angle of penetration
3	F	Commence drilling; recheck drill stem inclination to ensure that it is drilling at the correct angle
4	V	Proceed to drill the hole to the required depth
5	F	Remove the drill from the hole, check depth of hole (drill further if hole is too shallow) and prepare the machine for the move to the next hole.

In this case the fixed times are steps (1), (2), (3) and (5), because it would normally take the same time to carry out these steps at each hole position.

Step 4 is variable time, because it varies according to the depth of hole and type of rock being drilled.

Calculation of rate of production (e.g. in number of holes drilled per day, or total length in metres drilled per day) can be based on this analysis of fixed and variable components of the drill's operation. Figures for some steps may be available from past operations; otherwise, you will need to record times on site.

Section 2 – Assessment Activities

For information on how these assessment activities may be used as part of the learning process, see the section on 'Assessment' in the 'Topic Descriptor' section at the front of this topic.

Theory Questions

The following questions allow you to assess your progress in understanding the material presented in Section 2. The questions may be of any of the following types:

- multiple choice (identify correct answer or answers)
- multiple choice (identify incorrect answer or answers)
- fill in the gaps in a sentence or statement
- identify a sentence or statement as TRUE or FALSE
- write a few sentences or a short paragraph.

Answers to the question are shown in the separate 'Answer' section.

Question 1

One of the main aims of managing resources on site is to ensure that the company obtains the best possible value from them and that they are not wasted.

True ☐

False ☐

Question 2

Productivity is a measure of:

How fast a machine is operating. ☐

How hard the men on site are working. ☐

The outputs that a person or machine can achieve per unit of time. ☐

Whether the job has been achieved on time or not. ☐

Question 3

Put ticks in the appropriate boxes in the table to classify the following equipment items as Primary, Secondary or Static plant.

Equipment item	Primary	Secondary	Static
Dozer			
Crusher			
Compactor			
Scraper			
Grader			
Airtrac drill rig			
Dump truck			

Question 4

A dump truck driver spends time spotting the machine for loading, loading, hauling to the dump site, dumping the load and returning to the pit. Which of these operations represents fixed time?

____

Question 5

List four factors that affect the amount of time mobile equipment spends travelling.

____

____

____

____

Question 6

A person supervising mobile equipment on a construction job should:

Calculate cycle times as the operation proceeds. ☐

Check calculated cycle times on site with a stop watch. ☐

Only be concerned about the number of trips per hour if it they are obviously low. ☐

Aim to keep cycle times to a minimum. ☐

Question 7

Which of the following actions would be more effective in reducing travelling times of mobile equipment?

- Set up excavations so that primary plant is working downhill as much as possible. ☐
- Equip all plant items used to push material with rippers, so that they can rip soil or rock as required. ☐
- Spend extra time and effort in laying out haul roads. ☐
- Using a grader full-time to maintain haul roads. ☐

Question 8

If you are using dump trucks to shift material (pushed up by a dozer from a cut) to a fill 1.5 km away, which of the following statements would be correct?

- If the material is dry earth, it may be necessary to part-fill every truck to ensure it does not exceed the load limit. ☐
- If the material is wet clay, the load limit may be less than a truck load. ☐
- Dozer output may be reduced if the material being pushed up is difficult to load. ☐
- The method the dozer operator uses to push up the material should not depend on its weight. ☐

Question 9

Identify the correct statement or statements.

- A compacted cubic metre is one cubic metre of a material as it lies in its natural state. ☐
- A loose cubic metre is the volume that material occupies after it has been excavated from its natural state and allowed to expand. ☐
- A bank cubic metre is the volume that material occupies after it has been placed in a fill and compacted. ☐
- The swell that a material undergoes after removal from the natural state is expressed as a percentage of bank volume. ☐

Question 10

If you have to shift a volume of loose, dry gravel with a bank density of 1880 kg/cu m and a loose density of 1670 kg/cu m, what is the load factor?

____

____

Question 11

In the previous question, what is the per cent swell?

____

____

Question 12

The term 'struck capacity' refers to:

The volume of loose material in a container that is filled to overflowing. ☐

The volume of material that can be compacted into a container until it starts to overflow. ☐

The volume of loose material in a container that is filled exactly to level. ☐

The volume of material that can be compacted into a container until it is filled exactly to level. ☐

Question 13

The angle of repose of loose material is:

Often between 20° and 45°. ☐

Found by dividing horizontal distance by vertical. ☐

Found by dividing vertical distance by horizontal. ☐

The same for all loose materials. ☐

Question 14

The task efficiency factor for a grader:

Depends on the operator efficiency

Depends on the nature of the task, the local conditions and the type of machine

Is the combined efficiency factor minus the operator efficiency factor

Is greater when the grader is spreading materials bought by other machines.

Question 15

Name three factors that contribute to rolling resistance of a wheel loader operating on a soft clay surface.

____

____

____

Question 16

If a dozer has a favourable grade of 7%, what does it mean?

The dozer is moving uphill at 7% of its maximum speed. ☐

The dozer is moving downhill at 7% of its maximum speed. ☐

The dozer is moving uphill on a 7% gradient. ☐

The dozer is moving downhill on a 7% gradient. ☐

Question 17

Identify the correct statement or statements.

- Downhill operation reduces the weight of material the dozer has to push ahead of the blade. ☐
- A dozer working on the level needs less power than the same dozer working downhill. ☐
- A scraper operator will obtain better efficiency by loading loose gravel on a slight uphill grade. ☐
- When travelling downhill, a dozer must overcome both rolling resistance and grade resistance. ☐

Question 18

Two dozers in use on a construction job have the same power. When the operator of each machine selects first gear, we can say that:

- The drawbar pull will be the same for both machines. ☐
- The machine with higher kilograms pull will operate at a higher speed. ☐
- The speed will be the same for both machines. ☐
- The number obtained by multiplying kilograms pull by speed will be about the same for both machines. ☐

Question 19

What factors place limitations on the pulling power of a rubber-tyred scraper operating on a wet clay haul road?

Question 20

On a rubber-tyred dozer, the all-up weight is distributed between the driving and non-driving wheels. Only the weight placed on the driving wheels is available to do useful work.

True ☐

False ☐

Question 21

Add the missing words:

The time taken for a power-shift dozer to move into a selected gear and accelerate to gear speed is known as the______________________________________

Question 22

A front-end loader is loading trucks with gravel that has a carry factor of 0.9. Which of the following statements is correct?

The amount of gravel that the loader places into the truck tray each cycle is the same as the rated capacity of the bucket. ☐

The conversion factor from bank to loose cubic metres is 0.9. ☐

About 90% of the material picked up in the loader bucket ends up in the truck tray. ☐

About 90% of the material picked up in the bucket stays there as the material is lifted to the truck tray. ☐

Question 23

When planning an earthworks job, you have to choose between a few large dump trucks and a larger number of small tip trucks. Name three disadvantages that would apply if you chose the smaller trucks.

____

____

____

Question 24

Name three factors you would consider when deciding whether to load the trucks to struck or heaped capacity.

Question 25

On a construction job, you have a loader with a rated bucket capacity of 2.8 cu m, and dump trucks with a heaped capacity of 11 cu m. Are the loader and truck capacities balanced?

Question 26

Which of the following scraper cycles is likely to be the most efficient?

- One load, one spread, two turns; load uphill, spread downhill. ☐
- Two loads, two spreads, two turns; load uphill, spread downhill. ☐
- One load, one spread, two turns; load downhill, spread uphill. ☐
- Two loads, two spreads, two turns; load downhill, spread uphill. ☐

Question 27

On a construction job in a town centre, a grader needs to operate in passes of 90 m. It would be more efficient for the operator to reverse the machine, even though the reverse pass is unproductive.

True ☐

False ☐

Question 28

Classify the following machines as fixed or variable width by ticking the appropriate box.

Machine	Fixed width	Variable width
Dozer		
Paver		
Compactor		
Grader		

Question 29

If a grader is spreading gravel on site, which of the following factors would you consider if you needed to measure its output in square metres treated per hour?

- Speed, effective width and number of passes to complete the work. ☐
- Speed, effective width, efficiency factor and number of passes. ☐
- Speed, effective width, efficiency factor, depth of material treated and number of passes. ☐
- Speed, effective width, efficiency factor, depth of material treated, soil factor and number of passes. ☐

Question 30

When measuring the output of the grader spreading gravel, why is it important to measure the number of passes required to complete the work?

____

____

Question 31

What factors determine the output per worker in a construction work group?

____

____

Question 32

A circular slab of concrete has a diameter of 1.5 m and a depth of 300 mm. Which of the following calculations will give the volume of concrete in cubic metres?

π x 1.5 x 1.5 x 300

π x (1.5 x 1.5)/4 x 300

π x 1.5 x 1.5 x 0.3

π x (1.5 x 1.5)/4 x 0.3

Question 33

A cubic block of concrete has a volume of 27 cubic metres. What is the length of each side?

0.27 m

2.7 m

3 m

About 5.2 m

Question 34

A rectangular steel slab has a length of 2100 mm, a width of 900 m, and a depth of 50 mm. Which of the following calculations will give the volume of the slab in cubic metres?

2100 x 900 x 0.5

2100 x 900 x 50

2.1 x 0.9 x 0.5

2.1 x 0.9 x 0.05

Question 35

While calculating the corrected production for a dozer, you have read the uncorrected maximum production from the production curves and now need to multiply this figure by the applicable correction factors. List four correction factors that may apply.

Question 36

What is the difference between the cycle-time calculation for a tracked loader and that for a wheel loader?

Question 37

In a truck cycle, what is the waiting time, and how would you calculate it?

Question 38

What are the five amounts that are added together to give a truck's cycle time?

Question 39

What are the three times that are added together to give a scraper's cycle time?

Question 40

What is the basic method of measuring the cycle time for static equipment?

Question 41

Where would you obtain the information needed to answer Question 40?

Practical Exercises

Practical Exercise 1

On a site nominated by the assessor, and under supervision, measure up and calculate the bank volume of a specified mass of material. How much do you estimate the material weighs and how did you arrive at a figure? What would the volume be in the loose state?

Practical Exercise 2

On a site nominated by the assessor, and under supervision, measure the slope of a stockpile of material, or the slope of the ground on a roadway, haul road, batter or borrow pit. If you expressed the slope as an angle rather than a fraction, how did you convert your measurements of rise and run into an angle in degrees?

Practical Exercise 3

A grader working passes of 600 m has an operator efficiency factor of 50 minutes per hour and a task efficiency factor of 0.9. What is its combined efficiency factor?

Practical Exercise 4

From practical experience, would you say these are reasonable figures for a grader?

Practical Exercise 5

On a site nominated by the assessor, and under supervision, use a stop-watch to measure the cycle times of an item of static equipment (e.g. a crusher, screen, compressor or Airtrac drill). Which parts of the cycle are fixed (and which are variable) time?

Practical Exercise 6

On a site nominated by the assessor, and under supervision, use a stop-watch to measure the total time spent by trucks waiting to either load or unload. Why must this figure be measured directly on the job?

Practical Exercise 7

On a site nominated by the assessor, and under supervision, use a stop-watch to measure the total time spent by scrapers on each cycle. How many loads, hauls and turns are the scrapers making on each cycle ?

Practical Exercise 8

On a site nominated by the assessor, and under supervision, use a stop-watch to measure the cycle times of rollers or compactors. Are the machines' outputs on the job being measured in square metres or cubic metres per hour?

Practical Exercise 9

On a site nominated by the assessor, and under supervision, measure the dimensions of a variety of shapes associated with the job site, including (if possible) rectangles, cubes and cylinders. Calculate the areas in square metres or volumes in cubic metres, as appropriate.