SECTION 12A

PRODUCTIVITY

CONTENTS

CALCULATION OF PRODUCTION

When planning mechanized projects, one extremely important problem is how to calculate the production of the machines.
The first step when estimating the production is to calculate a theoretical value as explained below. This theoretical value is then adjusted according to actual figures obtained from past experience in similar operations.
On the basis of these figures (particularly those for job efficiency) it will be possible to determine values suitable for the project which will be neither over-optimistic nor wasteful.
Therefore it is first necessary to fully understand the theoretical calculations and to be able to obtain a figure for working efficiency which is feasible on that job site. From this it is possible to obtain a realistic figure for the work volume that can be attained.

Method of calculating production

It is usual to express the production of construction machines in terms of production per hour m^3/h or cu.yd./h).
This is basically calculated from the haul volume per cycle, and the number of cycles.

$$Q = q \times N \times E = q \times \frac{60}{Cm} \times E$$

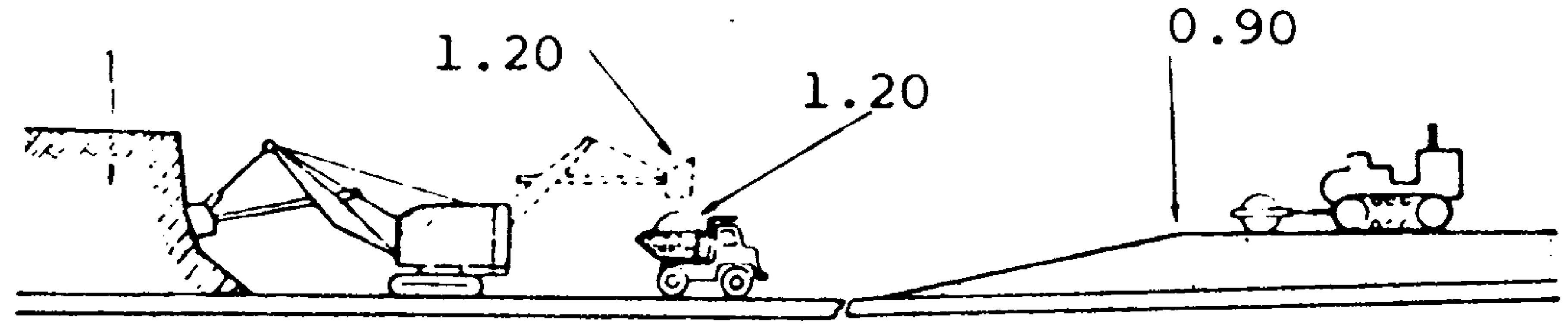
where Q : Hourly production (m^3/hr; cu. yd/hr)
q : Production (m^3; cu. yd) per cycle, of loose,excavated soil (This is determined by the machine capacity.)
N : NUMBER OF CYCLES PER HOUR $= \frac{60}{Cm}$
E : Job efficiency
Cm: Cycle time (in minutes)

1. Earth volume conversion factor (f)

The volume of any amount of earth depends on whether the soil is in its natural ground condition, (that is, unexcavated), whether it is loose, or whether it has been compacted.

This conversion factor depends on the type of soil and the operating state, but as a general rule, the values in the following table are used.

To obtain only the productivity of a construction machine, the earth volume conversion factor is taken as Table 1 and machine productivity is expressed in terms of loose earth. However, when planning actual projects, work volume is calculated in terms of unexcavated earth or compacted earth, so care must be taken to convert, these figures.



Changes in earth volume

Example:
1, 000m^3 of unexcavated earth has to be hauled.
a) What will its volume be when it has been excavated ready for hauling?
b) What will its volume be if it is then compacted?

	Unexcavated volume		Loose volume		Compacted volume
Ordinary soil:	1,000 m^3	× 1.25 =	1,250 m^3	→ 1,250 x 0.72 =	900 m^3
Gravel:	1,000 m^3	× 1.13 =	1,130 m^3	→ 1,130 x 0.91 =	1,030 m^3
Soft rock:	1,000 m^3	× 1.65 =	1,650 m^3	→ 1,650 x 0.74 =	1,220 m^3

[illegible] compact (Clay).
[illegible] Bank x 1.11
Loosed x 1.59
compact x 1.00

Ex. [illegible] A (Bank) [illegible] Bank × [illegible]
(clay) ([illegible]) " ——— " Loosed × 1.43.
" ——— " Compact × 0.90

Table 1 Earth volume conversion factor

Nature of earth	Initial condition of earth	Conditions of earth to be moved		
		Bank condition	Loosened condition	Compacted condition
Sand	(A)	1.00	1.11	0.95
	(B)	0.90	1.00	0.86
	(C)	1.05	1.17	1.00
Sandy clay	(A)	1.00	1.25	0.90
	(B)	0.80	1.00	0.72
	(C)	1.11	1.39	1.00
Clay	(A)	1.00	1.43	0.90
	(B)	0.70	1.00	0.63
	(C)	1.11	1.59	1.00
Gravelly soil	(A)	1.00	1.18	1.08
	(B)	0.85	1.00	0.91
	(C)	0.93	1.09	1.00
Gravels	(A)	1.00	1.13	1.03
	(B)	0.88	1.00	0.91
	(C)	0.97	1.10	1.00
Solid or rugged gravels	(A)	1.00	1.42	1.29
	(B)	0.70	1.00	0.91
	(C)	0.77	1.10	1.00
Broken limestone, sandstone and other soft rocks	(A)	1.00	1.65	1.22
	(B)	0.61	1.00	0.74
	(C)	0.82	1.35	1.00
Broken granite, basalt and other hard rocks	(A)	1.00	1.70	1.31
	(B)	0.59	1.00	0.77
	(C)	0.76	1.30	1.00
Broken rocks	(A)	1.00	1.75	1.40
	(B)	0.57	1.00	0.80
	(C)	0.71	1.24	1.00
Blasted bulky rocks	(A)	1.00	1.80	1.30
	(B)	0.56	1.00	0.72
	(C)	0.77	1.38	1.00

(A) Bank condition (B) Loosened condition (C) Compacted condition

[illegible] Loosed [illegible] Bank × 0.7
" ——— " Loosed × 1.0
" ——— " compact × 0.63.

2.Job efficiency(E)

When planning a project, the hourly productivity of the machines needed in the project is the standard productivity under ideal conditions multiplied by a certain factor. This factor is called job efficiency.

Job efficiency depends on many factors such as topography, operator's skill, and proper selection and disposition of machines.
In order that the value for job efficiency can anticipate changes in productivity, each combination of factors has its own value.

However, it is very difficult to give a value for job efficiency from a combination of many factors, as it requires a lot of skill.
Therefore, efficiency is given in the following section as a rough guide.

BULLDOZERS (DOZING)

The hourly production of a bulldozer when excavating or dozing is as follows:

$$Q = q \times \frac{60}{Cm} \times e \times E$$

where Q : Hourly production (m^3/hr; cu. yd/hr)
q : Production per cycle (m^3; cu. yd)
Cm: Cycle time (in minutes)
e : Grade factor
E : Job efficiency

1.Production per cycle(q)

For dozing operations, the blade capacity is theoretically caluculated as follows:

$$q = q_1 \times a$$

where q_1 : Blade capacity (m^3; cu. yd)
a : Blade factor

When calculating the stadard productivity of a bulldozer, the figure used for the volume of earth hauled in each cycle, was taken as blade capacity.In fact production per cycle differs with the type of soil, so the blade factor is used to adjust this figure.

Table 2 Blade Factor

Dozing conditions		Blade factor
Easy dozing	Full blade of soil can be dozed as completely loosened soil. Low water content,uncompacted sandy soil, general soil,stockpile material.	1.1--0.9
Average dozing	Soil is loose,but impossible to doze full blade of soil. Soil with gravel,sand,fine crushed rock.	0.9--0.7
Rather difficult dozing	High water content and sticky clay,sand with cobbles,hard dry clay and natural ground.	0.7--0.6
Difficult dozing	Blasted rock,or large pieces of rock	0.6--0.4

2.Cycle time(Cm)

The time needed for a bulldozer to complete one cycle(dozing, reversing and gear shifting) is calculated by the following formula:

$$Cm(min.) = \frac{D}{F} + \frac{D}{R} + Z$$

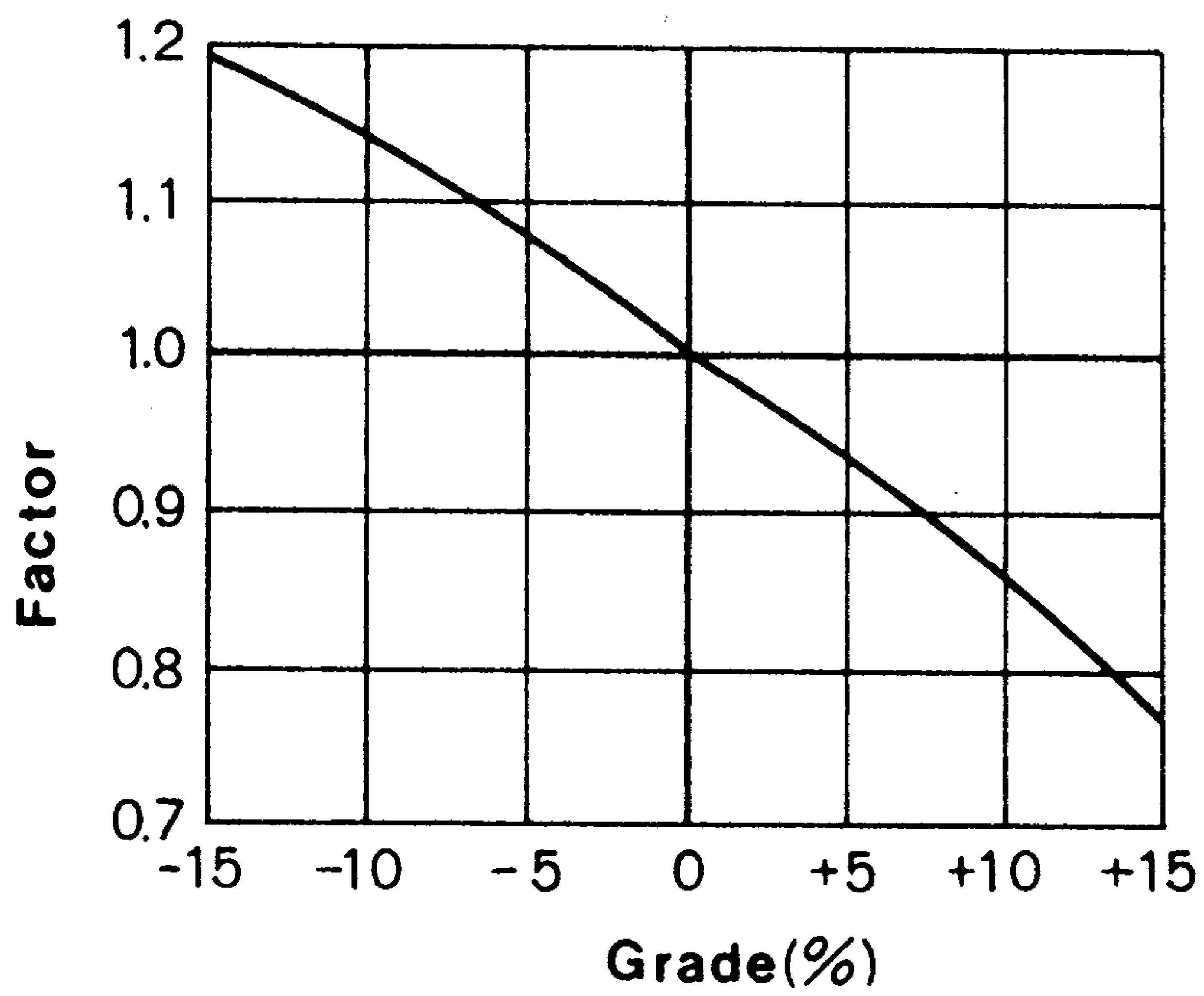
where D : Haul distance(m; yd)
F : Forward speed(m/min.; yd./min.)
R : Reverse speed(m/min.; yd./min)
Z : Time required for gear shifting(min.)

(1) Forward speed, reverse speed
As a rule a speed range of 3-5 km/h for forward, and 5-7 km/h for reverse should be chosen.

(2) Time required for gear shifting

	Time required for gear shifting
Direct-drive machine	0.10 min.
TORQFLOW machines	0.05 min.

3.Grade factor(e)



4.Job efficiency(E)

The following table gives typical job efficiency as a rough guide. To obtain the actual production figure, determine the efficiency in accordance with actual operating conditions.

Operating conditions	Job efficiency
Good	0.83
Average	0.75
Rather poor	0.67
Poor	0.58

(Ripping)

Ripping production varies greatly according to such conditions as the properties of the rock, the method of operation, and the operator's skill. Therefore, it is difficult to estimate. However, from available data, the relationship as shown on the ripper section can be seen between seismic velocity and production.

(Ripping and dozing)

In normal ripping operations, ripping and dozing operations are carried out repeatedly in turn.The combined production for ripping and dozing operations is calculated using the following formula.

$$Q = \frac{Q_R \times Q_D}{Q_R + Q_D}$$

Where Q = Ripping and dozing production
QR = Ripping production
QD = Dozing production

When making the calculation, it is necessary to use the same unit(natural rock position, loose rock condition, soil condition) for production QR and QD.

DOZER SHOVELS AND WHEEL LOADERS(LOADING)

Generally, the hourly production can be obtained by using the following formula:

$$Q = q \times \frac{60}{Cm} \times E$$

Where Q	:	Hourly production	(m^3/hr;cu.yd/hr)
q	:	Production per cycle	(m^3;cu.yd)
Cm	:	Cycle time	(min.)
E	:	Job efficiency	

1.Production per cycle(q)

$q = q_1 \times k$

where q_1 : The heaped capacity given in the specifications sheet

K : Bucket factor

(1) Bucket factor

Table 4 Bucket factor

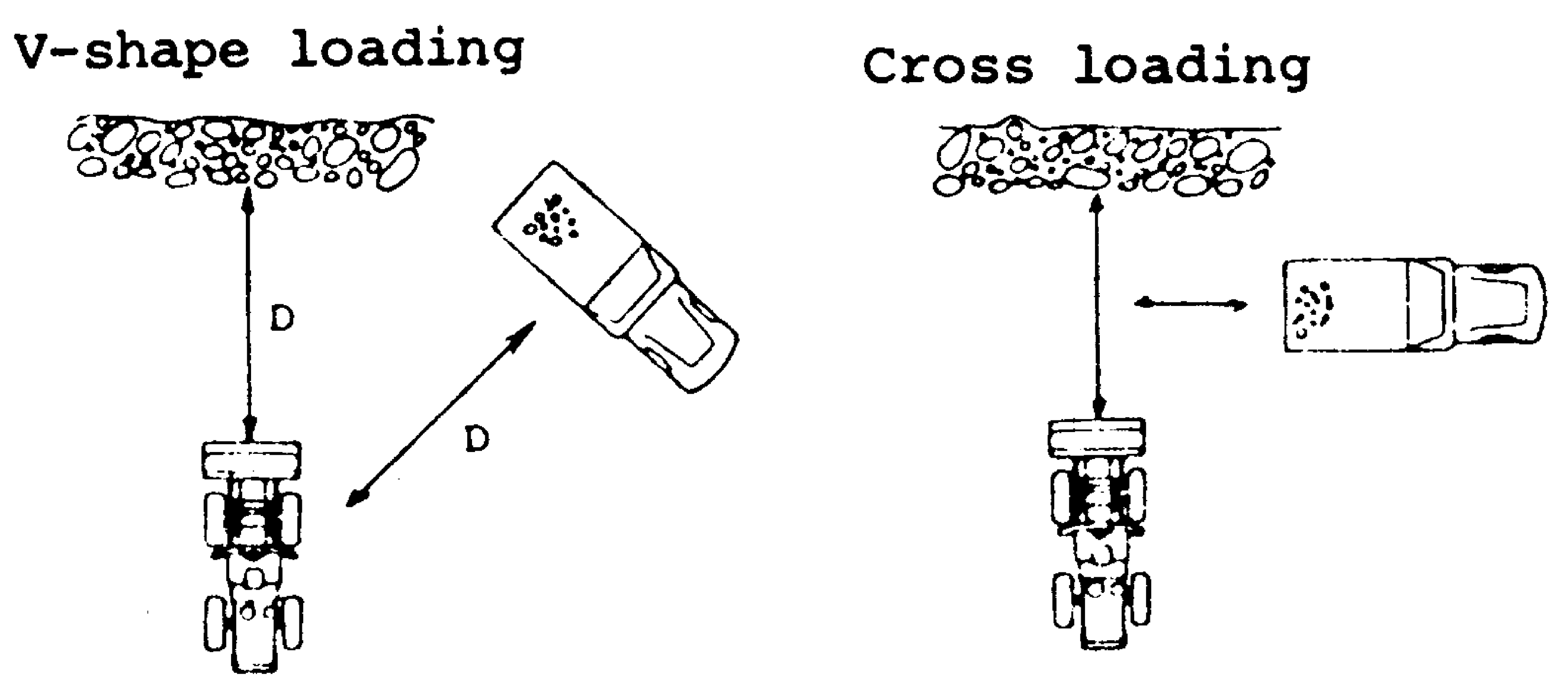
Loading condition	Wheel loader	Dozer shovel
Easy loading	1.0 ~1.1	1.0 ~1.1
Average loading	0.85~0.95	0.95~1.0
Rather difficult loading	0.8 ~0.85	0.9 ~0.95
Difficult loading	0.75~0.8	0.85~0.9

Table 3 Loading conditions

Operation conditions		Remarks
Easy loading (A)	Loading from a stockpile or from rock excavated by another excavator,bucket can be filled without any need for digging power. Sand,sandy soil,clayey soil with good water content conditions.	· Loading sand or crushed rock products · Soil gathering such as loading of soil dozed by a bulldozer.
Average loading (B)	Loading of loose stockpiled soil more difficult to load than category A but possible to load an almost full bucket. Sand,sandy soil,clayey soil,clay,unscreened gravel, compacted gravel,etc. Or digging and loading of soft soil directly in natural ground condition.	Digging and loading of sandy natural ground.
Rather difficult loading (C)	Difficult to load a full bucket. Small crushed rock piled by another machine. Finely crushed rock,hard clay,sand mixed with gravel,sandy soil,clayey soil, clay,clayey soil and clay with poor water content conditions.	Loading of small crushed rock
Difficult loading (D)	Difficult to load bucket,large irregular shaped rocks forming big air pockets. Rocks blasted with a explosives,boulders,sand mixed with boulders,sandy soil,clayey soil,clay,etc.	Loading of blasted rock

2.Cycle time(Cm)

The following tables show the standard cycle time according to loading method and operating conditions. It is possible to shorten a cycle time still more than the standard cycle time by minimizing a moving distance.



(1) V-shape loading

Table 5 Average cycle time for wheel loader

Unit: min.

Loading conditions \ Bucket size		~3m^3	3.1~5m^3	5.1m^3~
A	Easy	0.45	0.50	0.55
B	Average	0.55	0.60	0.65
C	Rather difficult	0.70	0.70	0.75
D	Difficult	0.75	0.75	0.80

Table 6 Average cycle time for dozer shovel

Unit: min.

Loading conditions \ Bucket size		~3m^3	3.1~5m^3
A	Easy	0.55	0.6
B	Average	0.60	0.7
C	Rather difficult	0.75	0.75
D	Difficult	0.80	0.80

(2) Cross loading

Table 7 Average cycle time for wheel loader

Unit: min.

Loading conditions \ Bucket size		~3m^3	3.1~5m^3	5.1m^3~
A	Easy	0.4	0.50	0.55
B	Average	0.5	0.60	0.65
C	Rather difficult	0.65	0.65	0.7
D	Difficult	0.7	0.75	0.75

Table 8 Average cycle time for dozer shovel

Unit: min.

Loading conditions \ Bucket size		~3m^3	3.1~5m^3
A	Easy	0.55	0.6
B	Average	0.6	0.7
C	Rather difficult	0.75	0.75
D	Difficult	0.8	0.8

3.Job efficiency(E)

The following table gives typical job efficiency as a rough guide. To obtain the actual production figure, determine the efficiency in accordance with actual operating conditions.

Operating conditions	Job efficiency
Good	0.83
Average	0.75
Rather poor	0.67
Poor	0.58

(LOAD AND CARRY)

$$Q = q \times \frac{60}{Cm} \times E$$

Where				
	Q	:	Hourly production	(m^3/hr;cu.yd/hr)
	q	:	Production per cycle	(m^3;cu.yd)
	Cm	:	Cycle time	(min.)
	E	:	Job efficiency	

1.Production per cycle(q)

$$q = q_1 \times K$$

Where q_1 : The heaped capacity given in the specifications sheet

K : Bucket factor

(1) Bucket factor

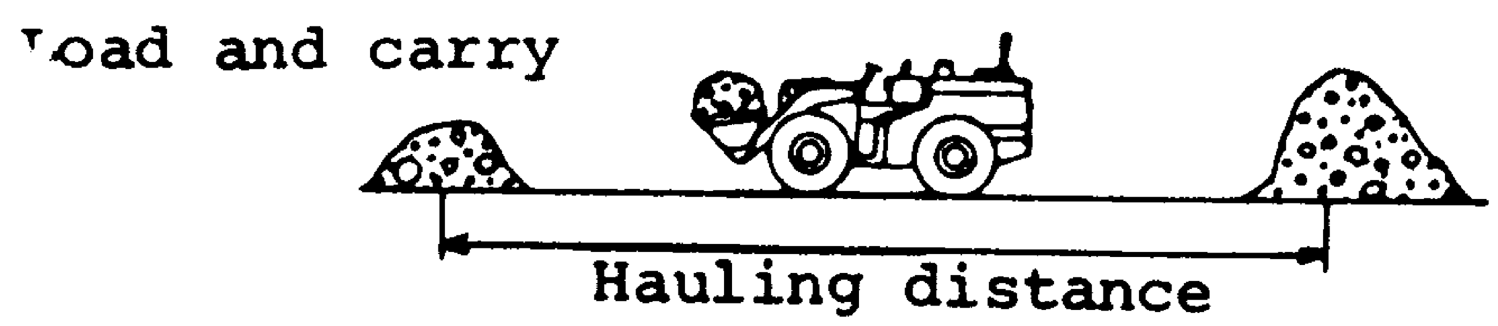
In a load and carry operation, fully heaped bucket cause soil spillage from bucket during hauling, so partially heaped bucket is recommendable.

Use the bucket factor of 0.7~0.9.

2.Cycle time(Cm)

$$Cm = \frac{D}{\frac{1000V_F}{60}} + \frac{D}{\frac{1000Ve}{60}} + Z$$

Where				
	D	:	Hauling distance	(m, yd)
	VF	:	Travel speed with load	(km/hr;MPH)
	VR	:	Return speed	(Km/hr;MPH)
	Z	:	Fixed time	(min)



(1) Travel speed

Operating conditions		Speed km/hr(MPH)	
		Loaded	Empty
Good	Hauling on well compacted flat road,few bumps in road surface,no meeting with other machines,can concentrate on L&C.	10~23 (6.2~14)	11~24 (6.8~15)
Average	Few bumps on road surface,flat road,some auxiliary work carrying large lumps of rock.	10~18 (6.2~11)	11~19 (6.8~12)
Rather poor	Bumps in road surface,high rate of auxiliary work.	10~15 (6.2~9.3)	10~16 (6.2~10)
Poor	Large bumps in road,meeting with other machines, difficult to carry out smooth work,large amount of auxiliary work.	9~12 (5.6~7.5)	9~14 (5.6~8.7)

(2) Fixed time(Z)

$$Z = t_1 + t_2 + t_3 + t_2$$

where				
	Z	:	0.60~0.75	(MIN.)
	t_1	:	Loading time	(0.20~0.35min.)
	t_2	:	Turning time	(0.15min.)
	t_3	:	Dumping time	(0.10min.)

3.Job efficiency(E)

The following table gives typical job efficiency as a rough guide. To obtain the actual production figure, determine the efficiency in accordance with actual operating conditions.

Operating conditions	Job efficiency
Good	0.83
Average	0.80
Rather poor	0.75
Poor	0.70

HYDRAULIC EXCACATORS

$$Q = q \times \frac{3600}{Cm} \times E$$

Where	Q	:	Hourly production	(m^3/hr;cu.yd/hr)
	q	:	Production per cycle	(m^3;cu.yd)
	Cm	:	Cycle time	(sec.)
	E	:	Job efficiency	

1.Production per cycle(q)

$$q = q_1 \times K$$

where q_1 : Bucket capacity (heaped)(m3;cu.yd)

K : Bucket factor

The bucket factor varies according to the nature of material.

A suitable factor can be selected from the table, taking into consideration the applicable excavatig conditions.

Table 9 Blade factor (Backhoe)

Excavating Conditions		Blade factor
Easy	Excavating natural ground of clayey soil,clay,or soft soil	1.1 ~ 1.2
Average	Excavating natural ground of soil such as sandy soil and dry soil	1.0 ~ 1.1
Rather difficult	Excavating natural ground of sandy soil with gravel	0.8 ~ 0.9
Difficult	Loading blasted rock	0.7 ~ 0.8

Table 10 Blade factor (Loading shovel)

Excavating Conditions		Blade factor
Easy	Loading clayey soil, clay, or soft soil	1.0 ~ 1.1
Average	Loading loose soil with small diameter gravel	0.95 ~ 1.0
Rather difficult	· Loading well blasted rock	0.90 ~ 0.95
Difficult	· Loading poorly blasted rock	0.85 ~ 0.90

2.Cycle time(Cm)

Cycle time = Excavating time + swing time(loaded) + dumping time + swing time(empty)

However, here we use cycle time = (standard cycle time) x (conversion factor).

The standard cycle time for each machine is determined from the following table.

Table 11 Standard cycle time for backhoe

Unit:sec

Model \ Range	Swing angle 45°~90°	Swing angle 90°~180°
PC60	10~13	13~16
PW60	10~13	13~16
PC80	11~14	14~17
PC100	11~14	14~17
PW100	11~14	14~17
PC120	11~14	14~17
PC150	13~16	16~19
PW150	13~16	16~19
PC180	13~16	16~19
PC200	13~16	16~19
PC210	14~17	17~20

Model \ Range	Swing angle 45°~90°	Swing angle 90°~180°
PW210	14~17	17~20
PC220	14~17	17~20
PC240	15~18	18~21
PC280	15~18	18~21
PC300	15~18	18~21
PC360	16~19	19~22
PC400	16~19	19~22
PC650	18~21	21~24
PC1000	22~25	25~28
PC1600	24~27	27~30

Table 11 Standard cycle time for loading shovel

Model	sec
PC400	16~20
PC650	18~22
PC1000	20~24
PC1600	27~31

Table 12 Conversion factor of backhoe

Digging condition (Digging depth / Specified max. digging depth)	Dumping condition: Easy (Dump onto spoil pile)	Normal (Large dump target)	Rather difficult (Small dump target)	Difficult (Small dump target requiring maximum dumping reach)
Below 40%	0.7	0.9	1.1	1.4
40~75%	0.8	1	1.3	1.6
Over 75%	0.9	1.1	1.5	1.8

3.Job efficiency(E)

The following table gives typical job efficiency as a rough guide. To obtain the atual production figure, determine the efficiency in accordance with actual operating conditions.

Operating conditions	Job efficiency
Good	0.83
Average	0.75
Rather poor	0.67
Poor	0.58

OFF-HIGHWAY DUMP TRUCKS

When carrying out operations using a suitable number of dump trucks of suitable capacity to match the loader, the operating efficiency is calculated in the following order:

1.Estimating the cycle time

The cycle time of a dump truck consists of the following factors.

(1) Time required for loader to fill dump truck
(2) Hauling time
(3) Time required for unloading(dumping)plus time expended for standby until unloading is started.
(4) Time required for returning
(5) Time required for dump truck to be positioned for loading and for the loader to start loading

Accordingly, the cycle time = (1) + (2) + (3) + (4) + (5)
The cycle time is calculated as follows:

Cycle time, Cmt

$$Cmt = n\ Cms + \frac{D}{V_1} + t_1 + \frac{D}{V_2} + t_2$$

Loading time (1)	Hauling time (2)	Dumping time (3)	Returning time (4)	Spot and delay time (5)

Where,

- n: Number of cycles required for loader to fill dump truck
  $n = C_1/q_1 \times K$
  - C_1: Rated capacity of dump truck (m^3, cu. yd.)
  - q_1: Dipper or bucket capacity (m^3) of loader
  - K: Dipper or bucket factor of loader
- Cms: Cycle time of loader (min)
- D: Hauling distance of dump truck (m, yd)
- V_1: Aeverage speed of loaded truck (m/min, yd/min)
- V_2: Average speed of empty truck (m/min, yd/min)
- t_1: Time required for dumping + time required for standby until dumping is started (min)
- t_2: Time required for truck to be positioned and for loader to start loading (min)

(1) Loading time

The time required for a loader to load a dump truck is obtained by the following calculation.

Loading time = Cycle time(Cms)X No.of cycles to fill dump truck(n)

(a) Cycle time of loader(Cms)

The cycle time of a loader is dependent on the type of loader(excavator, crawler type loader, wheel loader, etc.)

For the cycle time of loaders, refer to the section pertaining to the estimation of the production of loaders.

(b) Number of cycles required for loader to fill dump truck full(n)

The payload of a dump truck depends on its capacity or weight.

Where the payload is determined by the capacity,

$$n = \frac{\text{Rated capacity (m3, cu.yd) of dump truck}}{\text{Bucket capacity (m3, cu.yd)} \times \text{bucket factor}}$$

Where the payload is determined by the weight,

$$n = \frac{\text{Rated capacity (kg, lb) of dump truck}}{\text{Bucket capacity (m3, cu.yd)} \times \text{bucket factor} \times \text{specific weight}}$$

* The bucket capacity and the body capacity, as a general rule, refer to heaped capacity but may be used to refer to struck capacity depending on the nature of materials to be handled.

* The bucket factor is determined by the nature of soil to be excavated or loaded. In case of dozer shovels or wheel loaders a suitable factor can be selected from among those given in Table 4,9,10 according to the applicable loading conditions.

(2) Materials hauling time and returning time

The time taken to haul a load and return empty, can be calculated by dividing the haul road into sections according to the rolling resistance and grade resistance, as follows.

(a) Rolling resistance and grade resistance

As described above, the haul road is divided into several sections according to the rolling resistance and grade resistance. All of these rolling resistance and grade resistance values are summed up, resulting in the totals for each resistance.

The rolling resistance for the haul road conditions can be selected by referring to Table 13. The grade resistance can be obtained by averaging the gradients in all sections, which is converted(from degrees to percent). Table 14 indicates the grade resistance values(%) converted from the angles of gradients.

Table13 Rolling resistance

Haul road conditions	Rolling resistance
Well-maintained road,surface is flat and firm, properly wetted,and does not sink under weight of vehicle	2%
Same road conditions as above,but surface sinks slightly under weight of vehicle	3.5%
Poorly maintained,not wetted,sinks under weight of vehicle	5.0%
Badly maintained,road base not compacted or stabilized,forms ruts easily	8.0%
Loose sand or gravel road	10.0%
Not maintained at all,soft,muddy, deeply rutted	15 to 20%

Table 14 Grade resistance (%) converted from angle (°) of gradient

Angle	% (sin α)	Angle	% (sin α)	Angle	% (sin α)
1	1.8	11	19.0	21	35.8
2	3.5	12	20.8	22	37.5
3	5.2	13	22.5	23	39.1
4	7.0	14	24.2	24	40.2
5	8.7	15	25.9	25	42.3
6	10.5	16	27.6	26	43.8
7	12.2	17	29.2	27	45.4
8	13.9	18	30.9	28	47.0
9	15.6	19	32.6	29	48.5
10	17.4	20	34.2	30	50.0

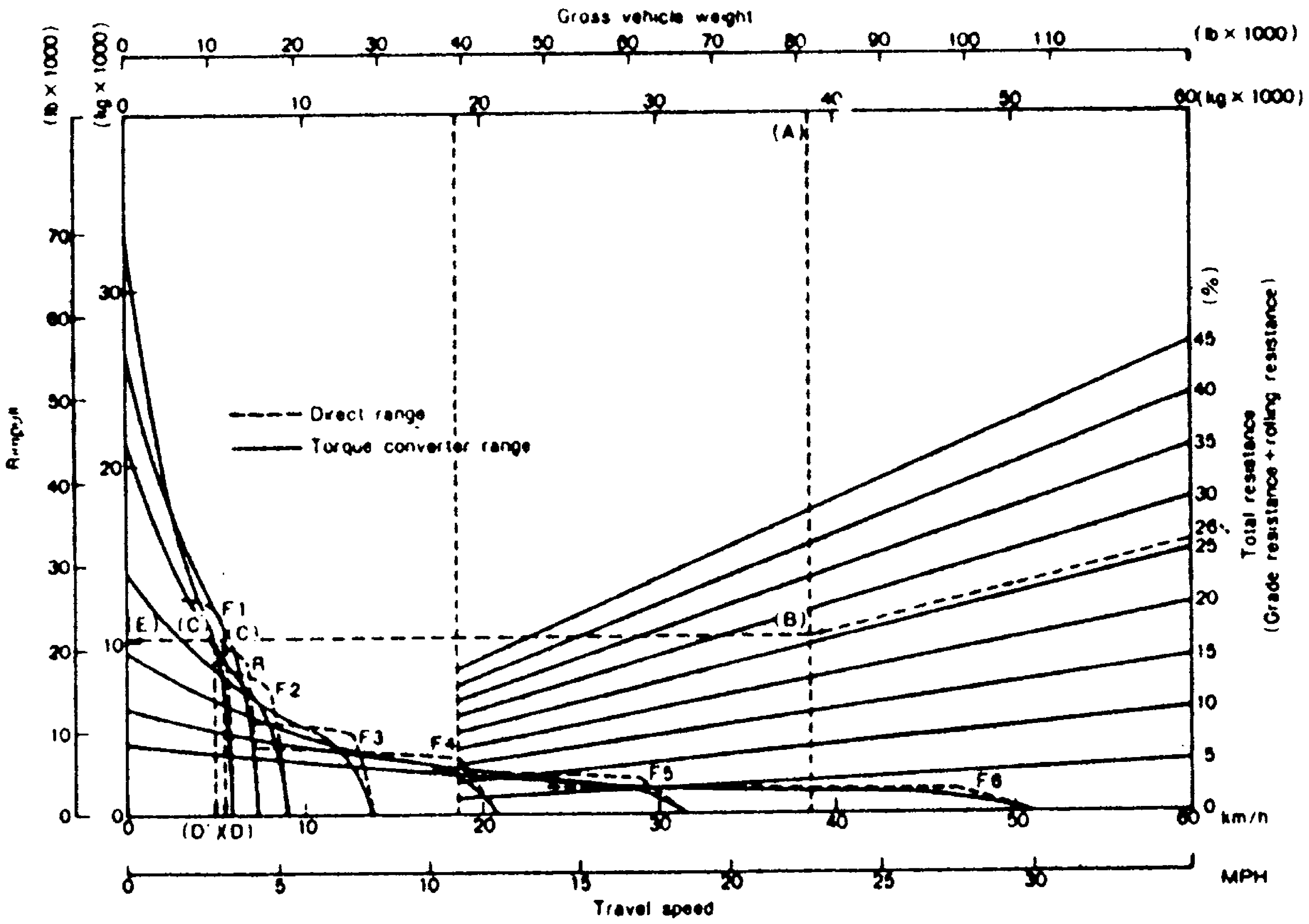
(b) Selection of the travel speed

The speed range suited to the resistance, and the maximum speed, can be obtained by using the Travel Performance Curve which appears in the product catalog.

To use, first draw a vertical line according to the vehicle's weight(A)and mark the point(B) corresponding to total resistance (the sum of rolling resistance and grade resistance).

Next, draw a horizontal line from(B), then mark(C) where the line intersects the rimpull curve and read(E) for the rimpull. For travel speed(D), draw a vertical line downward from (C). For instance, when traveling a 10% gradient and encountering a 4% rolling resistance, a vehicle with a 32-ton payload should have a rimpull of 8.3 tons and travel at a speed of 13.0 km/h(8.1 MPH)in forward 2nd gear.

Fig1 KOMATSU HD325-5 Dump Truck Travel Performance Curve



The maximum speed thus obtained is a theoretical value, and in order to convert this maximum speed to a practicable average speed, the speed should be multiplied by a speed factor. An applicable speed factor can be selected from the following table.

How to select a speed factor
If a truck is to start off downhill, gear-shifting to a desired speed can be accomplished in a short time. In such a case, a rather higher value should be used in each range of factors. On the other hand, if a truck is to start off on a level road or uphill, it will take a comparatively long time for gear-shifting to a desired speed to be accomplished and thus, the lower factor value should be selected in an applicable range of factors.

Table 15 Speed factors

Distance of each section of haul road, m	When making a standing start	When running into each section
0 - 100	0.25 - 0.50	0.50 - 0.70
100 - 250	0.35 - 0.60	0.60 - 0.75
250 - 500	0.50 - 0.65	0.70 - 0.80
500 - 750	0.60 - 0.70	0.75 - 0.80
750 - 1000	0.65 - 0.75	0.80 - 0.85
1000 -	0.70 - 0.85	0.80 - 0.90

Thus, the average speed can be obtained in the following manner:

$$\left(\begin{array}{l}\text{Max. vehicle speed obtained from}\\ \text{the travel performance curve}\end{array}\right) \times \text{(Speed factor)}$$

The above average speed is applicable in ordinary driving conditions. If there is any factor retarding the vehicle speed, an applicable factor should be used. The following can be cited as factors retarding a vehicle speed.

- Vehicles passing each other on a narrow road
- Sharp curve or many curves in the road
- Points giving poor visibility
- Narrow bridges or at railway crossings, intersections of roads
- Extreme differences in rolling resistance
- Pot-holes on the road
- Unexperienced or unskilled operators

These factors should be eliminated wherever possible.

(c) If the hauling distance in each section is divided by the average speed given in the preceding paragraph, the hauling time in each section will be obtained. If all of these times (for hauling and returning) are added together, they will give the total hauling and returning time.

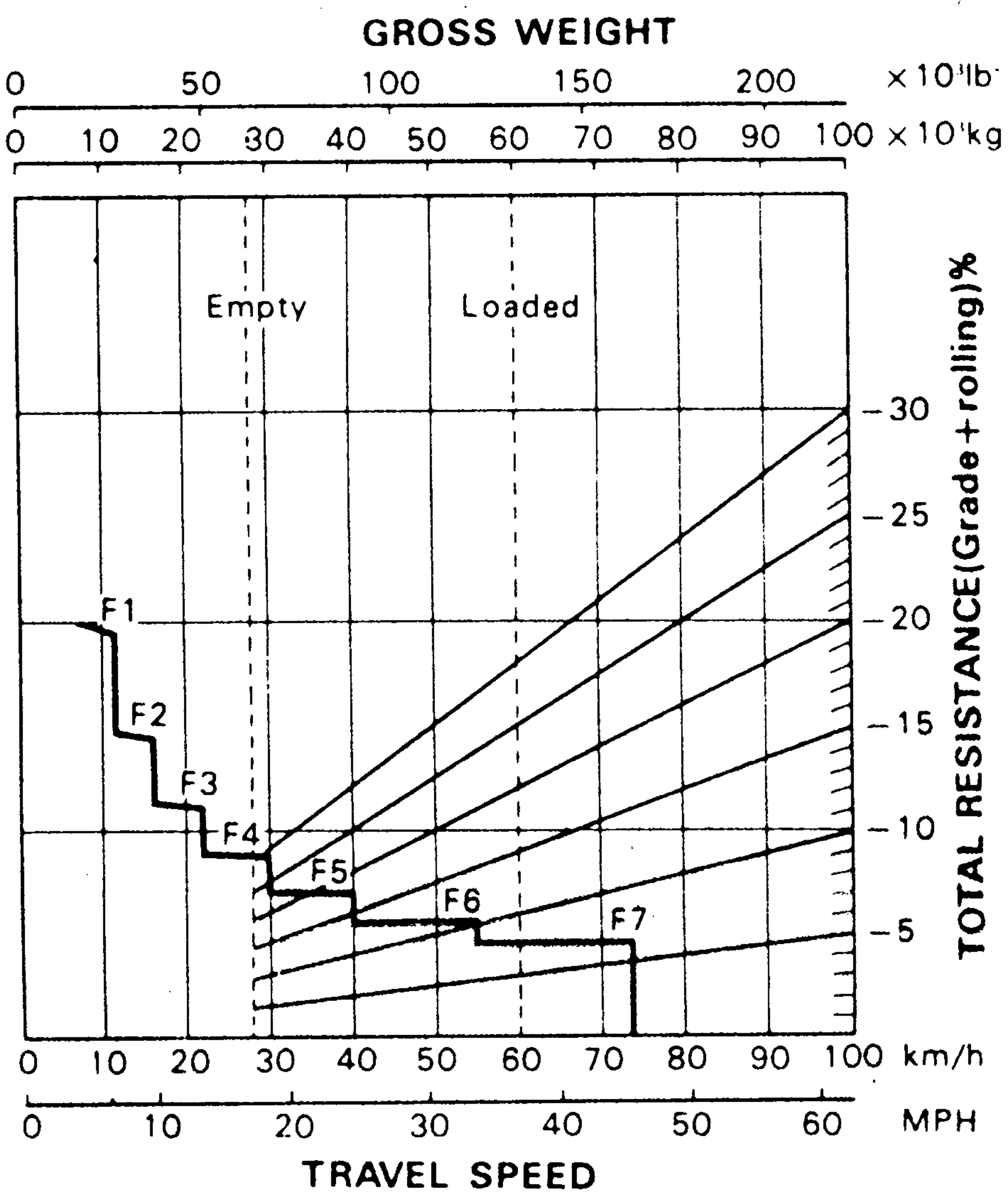
Hauling time and returning time in each section

$$= \frac{\text{length of section (m)}}{\text{Average speed (m/min)}}$$

(d) Vehicle speed limitation for a downhill run
Calculation of a vehicle speed as described in Paragraphs(a) to(c) is effected with the total resistance in % or in a plus value. If the total resistance is a minus value, the vehicle speed will ordinarily be limited by the retarder function with a given distance.
In the case of the HD325-5 dump truck, the

maximum speed at which the truck can safely go down a hill can be obtained in the brake performance curve in Fig. 2. (Grade distance continuous).
For example, assume the total resistance is-10% (gradient resistance is -12% plus rolling resistance +2%) on the "continuous grade" graph. First, draw a vertical line from the total vehicle weight(A) so that it crosses the slanted line of 10% total resistance(B). From(B), draw a horizontal line to the left and it will cross the stair curve(C).
Finally, draw a vertical line from(C) and read(D) the maximum speed for driving safely down the slope. In this case, a vehicle with a 32-ton payload should travel at approximately 30 km/h(18.6 MPH) in forward 4th gear.

Fig2 HD325-5 Brake Performance (Grade distance continuous)



(3) Dumping time t_1

This is the period from the time when the dump truck enters the dumping area, to the time when the dump truck starts its return journey after completing the dumping operation. The length of the dumping time depends on the operating conditions, but average dumping times for favorable, average and unfavorable conditions are given by the following table.
However, particularly adverse conditions giving rise to extremely long dumping times are excluded.

Operating conditions	t_1, min.
Favorable	0.5 to 0.7
Average	1.0 to 1.3
Unfavorable	1.5 to 2.0

t_2 (4) Time required for the truck to be positioned and for the loader to begin loading

The time taken for the truck to be positioned and for the loader to begin loading also depends on the operating conditions. As a general rule, a suitable time can be selected from the table below.

Operating conditions	t_2, (min.)
Favorable	0.1 to 0.2
Average	1.25 to 0.35
Unfavorable	1.4 to 0.5

As has so far been described, the cycle time of a dump truck can be estimated by using the values for factors obtained according to paragraph (1) to (4).

2. Estimating the number of dump trucks required

The quantity of dump trucks required for use in combination with a loader working at its maximum operating efficiency can be estimated by the following formula:

$$M = \frac{\text{Cycle time of a dump truck}}{\text{Loading time}} = \frac{Cmt}{n \times Cms}$$

Where,
- n : Number of cycles required for a loader to fill a dump truck
- Cms : Cycle time of loader (min)
- Cmt : Cycle time of dump truck (min)

3.Estimating the productivity of dump trucks

The total hourly production P of several dump trucks where they are doing the same job simultaneously is estimated by the following formula:

$$P = C \times \frac{60}{Cmt} \times E_t \times M$$

Where,
- P : Hourly production (m^3/h)
- C : Production per cycle $C = n \times q_1 \times K$
- E_t : Job efficiency of dump truck
- Cmt : Cycle time of dump truck
- M : Q'ty of dump trucks in operation

The following table gives typical job efficiency as a rough guide. To obtain the actual productoion figure, determine the efficiency in accordance with actual operating cinditions.

Table 16 Job efficiency of dump truck (Et)

Operating conditions	Job efficiency
Good	0.83
Average	0.80
Rather poor	0.75
Poor	0.70

4.Combined use of dump trucks and loaders

When dump trucks and loaders are used in combination, it is most desirable that the operating capacity of the dump trucks be equal to that to the loaders. That is, conditions satisfying the following equation are most desirable. Consequently, if the value of the left equation is larger, the group of dump trucks has a surplus capacity.
On the other hand, if the value of the right equation is larger, the group of loaders has a surplus capacity.

$$C \times \frac{60}{Cmt} \times E_t \times M \geq q_1 \times K \times \frac{60}{Cmt} \times E_s$$

The left equation has already been described. The right equation has the following meaning.

- **Cms : Cycle time of a loader(min)**
- **E_s : Job efficiency of loader**
- **q_1 : Bucket capacity(heaped (m^3))**
- **k : Bucket factor**

EXAMPLE

- An HD325,working in combination with a WA600,is hauling excavated much to a spoil-bank 500 meters away. What is the hauling capacity of the HD325?

Working conditions for dump truck:

Haul distance : flat road: 450
slope: 50m
gradient of slope: 10%

Haul road condition : Road with sunken surface, not wetted, poorly maintained.

Type of soil : Sandy clay (loose density 1.6 tons/cu.m)
Job efficiency : 0.83 (good operating conditions)
Speed limits : For safety purposes, the following maximum speeds should not be exceeded.

		Speed
Flat	Loaded	40 km/h
	Unloaded	60 km/h
Uphill	Loaded	20 km/h
	Unloaded	40 km/h
Downhill	Loaded	20 km/h
	Unloaded	40 km/h

Wheel Loader : Bucket capacity : $5.4m^3$ (7.1cu.yd)
Cycle time : 0.65min
Bucket factor : 0.9
Job efficiency : 0.83

Answer

(a) Cycle time(Cmt)

(i) Loading time

Cycle time of loader Cms = 0.65min

Number of cycles required for loader to fill dump truck

$$n = \frac{\text{Rated capacity of dump truck}}{\text{Bucket capacity} \times \text{Bucket factor} \times \text{Loose density}}$$

$$= \frac{\text{32tons(max. payload)}}{5.4m^3 \times 0.9 \times 1.6} = 4.12$$

n is taken to be 4.
Loading time = n × Cms = 4 × 0.65 = 2.60min.

(ii) Hauling time and returning time

The hauling distance is divided up and the time taken to cover each section calculated.

Hauling : 1 Flat 330m
2 Uphill 50m
3 Flat 120m

Returning : 4 Flat 120m
5 Downhill 50m
6 Flat 330m

Net weight of dump truck(unloaded) 27,200kg
(figure in catalogue)

Loaded weight

Weight when loaded = n × bucket capacity × bucket factor × loose specific gravity × 1, 000
= $4 \times 5.4m^3 \times 0.9 \times 1.6 \times 1,000$
= 31, 104kg

Weight of loaded dump truck = 27, 200kg + 31, 104kg
= 58, 304kg

Using the Travel Performance Curve and Brake Performance Curve, the maximum speed for each section can be calculated.
The values for HD325 can be calculated from Fig. 1 and Fig. 2.

(iii) **Dumping time and standby time**

t_1 = 1.15 min. (average)

(iv) **Time required for the dump truck to be positioned for loading, and for the loader to start loading**

t_2 = 0.3min. (average)

(v) **Cycle time**

Cmt = 2.60 + 3.00 + 1.15 + 0.3 = 7.05min.

(b) Estimating the production of dump truck

$$P = C \times \frac{60}{Cmt} \times Et = 19.44 \times \frac{60}{7.05} \times 0.83$$

$$= 137.3 m^3/h$$

$$C = n \times \text{bucket capacity} \times \text{bucket factor}$$

$$= 4 \times 5.4 \times 0.9$$

$$= 19.44 m^3$$

		Dis-tance	Grade Resist-ance	Rolling Resist-ance	Total Resist-ance	Speed Range	Max.Travel Speed	Speed Factor	Ave. Speed	Time Taken
Loaded	Flat	330	0	5%	5%	F5	36km/h (600m/min)	0.50	300.0m/min	1.10min
	Uphill	50	10 %	5%	15%	F2	11km/h (183m/min)	0.60	109.8m/min	0.46
	Flat	120	0	5%	5%	F5	36km/h (600m/min)	0.60	300.0m/min	0.40
Unloaded	Flat	120	0	5%	5%	F6	53km/h (883m/min)	0.35	309.1m/min	0.39
	Downhill	50	– 10 %	5%	– 5%	F6	*40km/h (667m/min)	0.70	466.9m/min	0.11
	Flat	330	0	5%	5%	F6	53km/h (883m/min)	0.70	618.1m/min	0.54
									Total	3.00min

*In the Brake Performance Curve (Fig. 2), the figure for total resistance is given as -5%. This means that when driving unloaded and using the speed range F6 as shown in the diagram, it is enough to press the accelerator pedal and keep within the speed limit.

MOTOR SCRAPERS

The production of a motor scraper can be estimated by using the following formula:

$$Q = q \times \frac{60}{Cm} \times E$$

Where
- Q : Hourly production(m^3/hr;cu.yd/hr)
- q : Production per cycle(m^3;cu.yd)
- Cm : Cycle time(min)
- E : Job efficiency

1.Production per cycle(q)

$$q = q_1 \times K$$

Where
- q_1 : The heaped capacity given on the specifications sheet
- K : Payload factor

The amount of soil that can be loaded into the bowl of the motor scraper depends on the type of soil that is to be handled or hauled. The table below should be used to determine the payload factor.

Type of materials	Payload factor
Sand	0.90
Sandy clay	0.80
Clay	0.70
Dense, heavy clay or sand mixed with boulder	0.65

2.Cycle time(Cm)

The cycle times are calculated by using the following formulas.

Cm = Loading time + Hauling time + Spreading and turning time + Return time + Spot and delay time

(1) Loading time

Loading time is generally dependent on the following items.

(a) Type and capacity of scraper
(b) Type of pusher
(c) Type of earth to be loaded
(d) Condition of borrow-pit
(e) Skill of operator

If the loading operation is performed by a WS16 and WS23S assisted by a pusher in the D155-tractor and D355-tractor class respectively, the load time will vary depending on the loading conditions as follows:

Loading conditions	Loading time (min)
Excellent	0.5
Average	0.6
Unfavorable	1.0

(2) Hauling time and returning time

The hauling and returning time can be calculated by using the Travel Performance Curve of the motor scraper given in the specification sheets. First, divide the motor scraper operating site into sections according to grade and rolling resistances, and calculate the total resistance of each section.

(a) Rolling and grade resistance

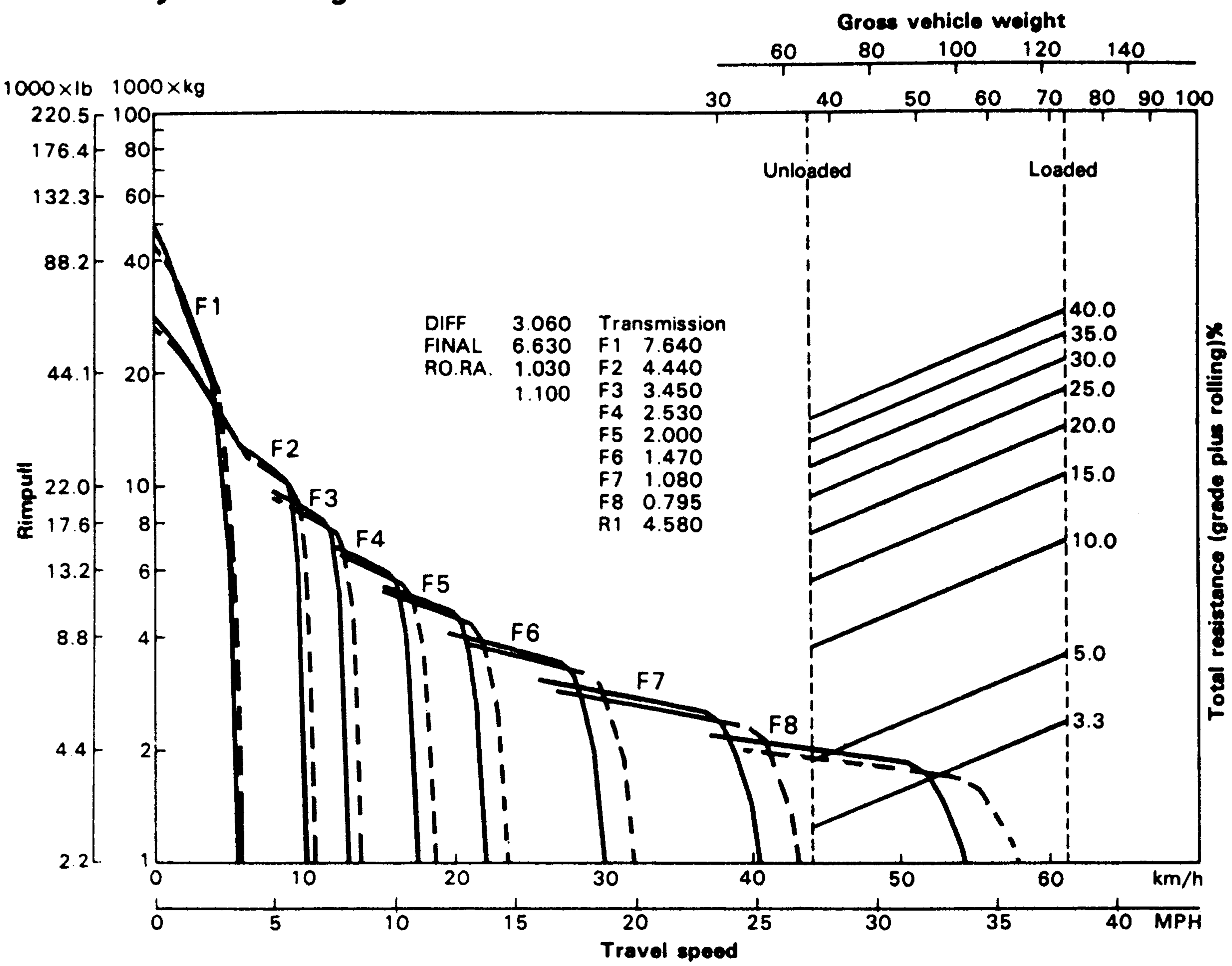
The total resistance in the travel performance curve of a motor scraper is the sum of the rolling and grade resistances.

(b) Selection of the travel speed

Second, obtain the travel speed of the vehicle in each section by using the Travel Performance Curve. The speed is calculated in the same way as for dump trucks.

The values obtained are the theoretical maximum speeds, and vary according to the actual operation.

KOMATSU ××× Motor Scraper Travel Performance Curve



Speed factor

The maximum speeds obtained in the above procedure must be converted to average speeds by using a conversion factor called the speed factor.

The speed factor range differs depending on whether the vehicle makes a standing start or whether it enters the section while traveling.

Where the vehicle enters the section while traveling, a higher factor must be used on a downhill and a lower factor on an uphill.

Distance of each section of haul road (m)	Wher vehicle makes standing start	Where vehicle enters a section while traveling
0 - 150	0.30 - 0.45	0.55 - 0.60
150 - 300	0.45 - 0.60	0.60 - 0.70
300 - 500	0.50 - 0.65	0.65 - 0.75
500 - 700	0.60 - 0.70	0.75 - 0.85
700 - 1000	0.65 - 0.75	0.80 - 0.90
1000 -	0.70 - 0.85	0.85 - 0.95

Average travel speed
The average travel speed can be obtained by using a formula,

Average travel speed = Max. travel speed x speed factor

Total hauling and returning time

Hauling time or returning time in each section =

$$\frac{\text{Length of section (m)}}{\text{Average speed (m/min)}}$$

(3) Spread and turn time

The spreading and turning time covers the period from the time when the scraper enters the spreading area from the haul road to the time when the vehicle enters the return road after spreading and making a turn in the spreading area.

The spreading and turning time can be selected from among the values given below.

Spreading condition	Spreading and turning time (min)
Excellent	0.4
Average	0.6
Unfavorable	1.1

(4) Spot and delay time

The spot and delay time is the total of the time required for making turns in the borrow pit, idle run in gearshifting, and for awaiting the pusher, the idle time in selecting a borrow pit, etc. This spot and delay time can be selected from among the values given below.

Conditions	Spot and delay time
Excellent	0.3 min
Average	0.5 min
Unfavorable	0.8 min

Thus, the cycle time can be calculated by following the above procedures.

3.Job efficiency(E)

The following table gives typical job efficiency as a rough guide. To obtain the atual production figure, determine the efficiency in accordance with actual operating conditions.

Operating conditions	Job efficiency
Easy	0.83
Average	0.80
Rather difficult	0.75
Difficult	0.70

MOTOR GRADERS

The motor grader is used for many purposes such as maintaining roads, final finishing for earthmoving projects, trenching and bankcutting.
Therefore there are many methods of expressing its operating capacity.

1.Calculating the hourly operating area(m^2/h)

$$Q_A = V \times (L_e - L_o) \times 1000 \times E$$

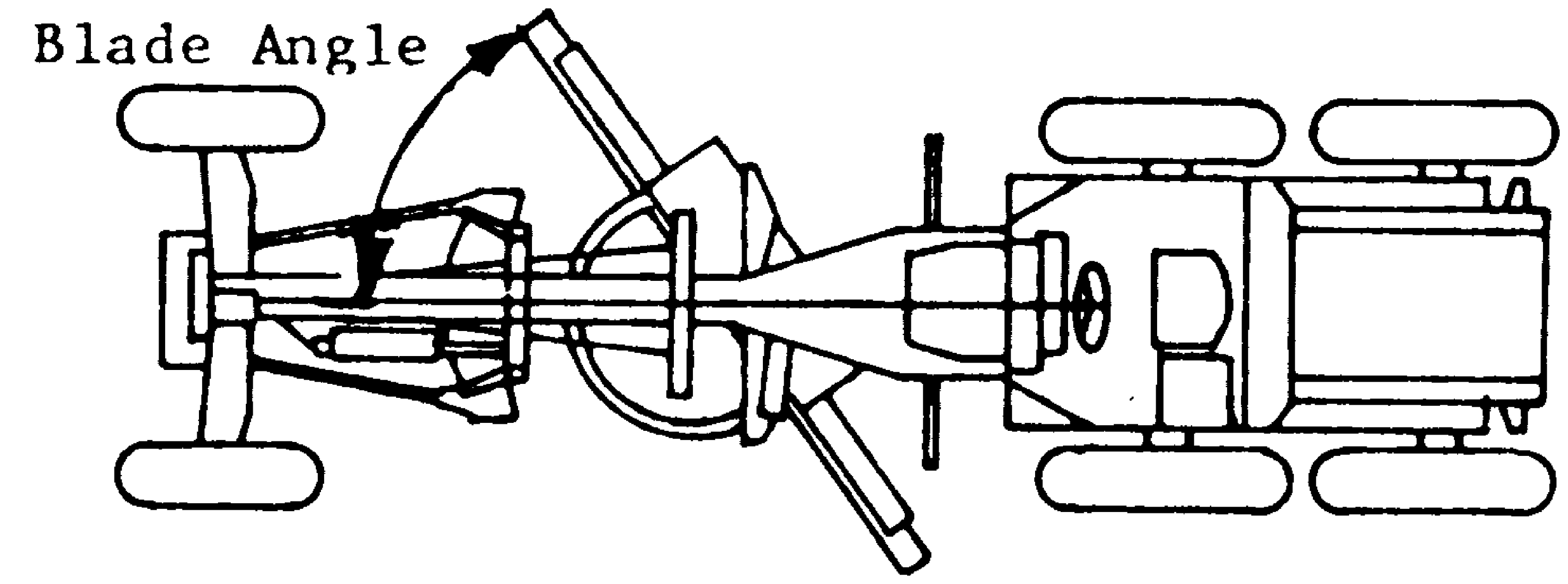
Where Q_A : Hourly operating area (m^2/hr)
V : Working speed (km/hr)
L_e : Effective blade length (m)
L_o : Width of overlap (m)
E : Job efficiency

Note : Graders usually operate on long stretches, so the time required for gear shifting or turning can be ignored.

(1) Working speed(V)

Road repair :	2 to 6 km/h
Trenching :	1.6 to 4 km/h
Bank finishing :	1.6 to 2.6 km/h
Snow-removal :	7 to 25 km/h
Field grading :	1.6 to 4 km/h
Leveling :	2 to 8 km/h

(2) Effective blade length(Le), width of overlap(Lo)
Since the blade is normally angled when cutting or grading the surface, the effective blade length depends on the angle.
The width of overlap is usually 0.3 m. The following table gives the values to be used when applying the formula.



Blade length (m)	Effective blade length (m)	
	Blade angle 60°	Blade angle 45°
2.2	1.9	1.6
2.5	2.2	1.8
2.8	2.4	2.0
3.05	2.6	2.2
3.1	2.7	2.2
3.4	2.9	2.4
3.7	3.2	2.6
4.0	3.5	2.8
4.3	3.7	3.0
4.9	4.2	3.5

(3) Job efficiency(E)

The following table gives typical job efficiency as a rough guide. To obtain the atual production figure, determine the efficiency in accordance with actual operating conditions.

Operating conditions	Job efficiency
Rood repair, leveling	0.8
Snow-removal (V-type plow)	0.7
Spreading, grading	0.6
Trenching, snow-removal	0.5

2. When calculating the time required to finish a specific area.

$$N = \frac{N \times D}{V \times E}$$

Where T = Working time (h)

N = Number of trips

D = Working distance (km)

V = Working speed (km/hr)

E = Job efficiency

Number of trips(N)

When a grader is operating in a job site, and levelling parallel strips, the number of trips can be calculated by using the following formula:

$$N = \frac{W}{Le - Lo} \times n$$

Where W : Total width to be levelled (m)

Le : Effective blade length (m)

Lo : Width of overlap (m)

n : Number of gradings reguired to finish the surface to the required flatness.

COMPACTORS

There are two ways of expressing the productivity of compactors: by the volume of soil compacted, and by the area compacted.

1. Expressing productivity by the volume of soil compacted.

When calculating the productivity by the volume of soil compacted, the following formula is used.

$$Q = \frac{W \times V \times H \times 1000 \times E}{N}$$

Where

Q = Hourly production (m^3/hr) (volume of soil compacted)

V = Operating speed (km/hr)

W = Effective compaction width per pass (m)

H = Compacted thickness for one layer (m)

N = Number of compaction (number of passes by compactor)

E = Job efficiency

(1) Operating speed(V)

As a general rule the following values are used.

Road roller	about 2.0 km/hr
Tire roller	about 2.5 km/hr
Vibration roller	about 1.5 km/hr
Soil compactor	4 – 10 km/hr
Tamper	about 1.0 km/hr

(2) Effective compaction width(W)

Type of Equipment	W
Macadam roller	Driving wheel width – 0.2 m
Tandem roller	Driving wheel width – 0.2 m
Soil compactor	(Driving wheel width × 2) – 0.2 m
Tire roller	Outside-to-outside distance of most outside tires – 0.3 m
Large vibratory roller	Roller width – 0.2 m
Small vibratory roller	Roller width – 0.1 m
Bulldozer	(Width of track shoe x 2) – 0.3 m

(3) Compacted thickness for one layer

Compacted thickness is determined from compaction specifications or from the results of tests, but as a general rule, it is 0.2~0.5 min loosend soil.

(4) Number of compaction passes(N)

The number of passes is also determined from the construction specifications, or from the results of tests, but as a general rule, the following values are used.

Tire roller	3 – 5
Road roller	4 – 8
Vibration roller	4 – 12
Soil compactor	4 – 12

(5) Job efficiency(E)

This is expressed by the actual working time rate (effective working time hour).

2. Expressing productivity by the area compacted

$$QA = \frac{W \times V \times 1000 \times E}{N}$$

Where QA : Hourly area (m^2/hr)

3.Example

Hourly production(area) of the work having following conditions is calculated:

Conditions

Machine : Komatsu vibratory roller JV32W

Effective compaction width :

W : 0.8m (= 1.0 – 0.2m)

Operating speed :

V = 1.6km/h (lst, F or R)

No. of compaction passes:

P = 8 passes

Answer

$$Q_A = \frac{W \times V \times 1000 \times E}{N} \quad \text{(where, E = 0.65)}$$

$$= \frac{0.8 \times 1.6 \times 1000 \times 0.65}{8} = 104 m^2/h$$