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Modelling Truck Performance In A Spreadsheet

Alan Cooper, Principal Mining Consultant, Snowden Mining Consultants

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87 Colin Street West Perth WA 6005

PO Box 77 West Perth WA 6872

Tel + 61 8 9213 9213

Fax + 61 8 9322 2576

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Snowden
87 Colin St West Perth WA 6005 Australia
PO Box 77 West Perth WA 6872 Australia
Telephone: +61 8 9213 9213
Facsimile: +61 8 9322 2576
Website: http://www.snowdengroup.com

Alan Cooper
Principal Consultant Mining Engineer
acooper@snowdengroup.com

Introduction

Most open pits today are mined using the truck and shovel mining system (refer Figure 1). These operations usually model their mining schedules and cost models using a spreadsheet. However, truck performance and ultimately haulage requirements (that is truck numbers) are usually modelled in a specialised truck haulage program such as TALPAC[1]. As discussed here, truck performance and haulage requirements can be modelled in a spreadsheet, there are some simple formulas which can be applied with significant benefits.

Figure 1 Truck and shovel in operation

[1] A Runge Limited software package

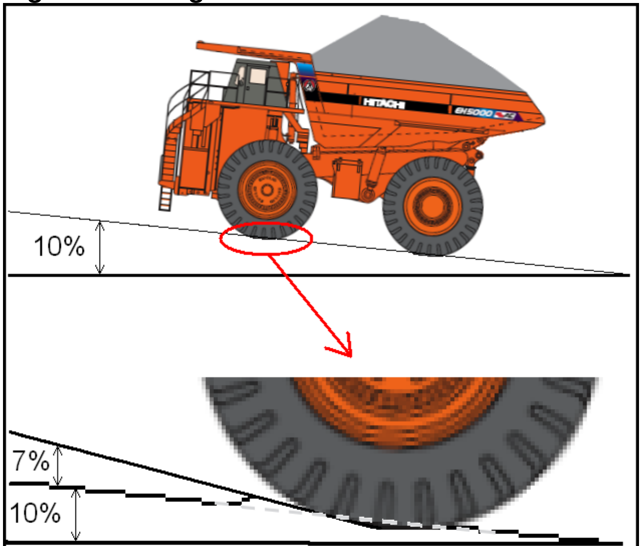
Modelling Truck Performance in a Spreadsheet

The physics or mathematics behind the truck performance is not difficult and the results match well with truck manufacturers' performance graphs. The calculation of fuel burns is also presented here. Fuels burns are of interest because of the impact of increasing fuel prices and because they are often based on historical usage rather than calculated as part of the truck performance.

The physics of a truck

The up ramp truck speed is dependant on the energy available from the engine to lift the truck weight, including its payload, against gravity and to overcome rolling resistance and transmission losses (refer Figure 2 and Equation 1).

Figure 2 Rolling resistance model[2]



Tyre penetration into the road surface is the main cause of rolling resistance (a little exaggerated).

Equation 1: Up ramp truck speed

$$\text{UpRampTruckSpeed} = \frac{3.6 * \text{GrossEnginePower} * \text{TransmissionEfficiency} * (1 + \text{RampGrade} * \text{RampGrade})^{\wedge}0.5}{\text{TotalTruckWeight} * 9.81 * (\text{RampGrade} + \text{RollingResistance})}$$

The down ramp truck speed is dependant on the energy that engine can absorb generated by the truck running down hill from gravity but less rolling resistance and transmission losses (refer Equation 2).

[2] Truck image downloaded from www.hitachimining.com

Equation 2: Down ramp truck speed

$$DownRampTruckSpeed = -\frac{3.6*GrossEnginePower*RetarderFactor*(1+RampGrade*RampGrade)^{0.5}}{TotalTruckWeight*9.81*(RampGrade+RollingResistance)}$$

In both cases the maximum truck speed needs to be limited to the manufacturer's recommendation. Further speed restrictions may be applied for site specific (i.e. safety) reasons. The gross engine power (in kilowatts), trucks weights [maximum and unloaded (in tonnes)] are published in the truck manufactures manuals.

The transmission efficiency factor and the retarder factor are used to calibrate the model to the manufacturer's performance graph. An 80% transmission efficiency and a 115% retarder factor seems to work universally.

Figure 3 shows the model plotted against the Caterpillar 777D truck (using the performance graph and assuming 3% rolling resistance, refer Figure 4). The up ramp performance calibration is very good. The down ramp performance approximates the "gear" speeds. This is considered sufficient for most applications.

Figure 3 Truck Model Calibration

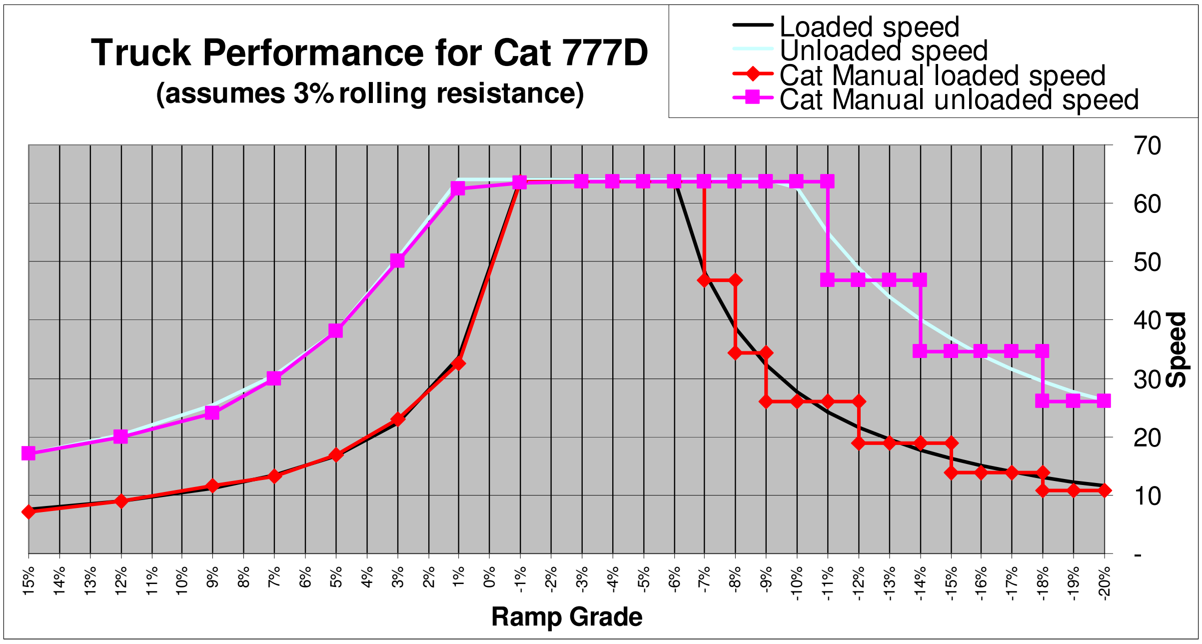
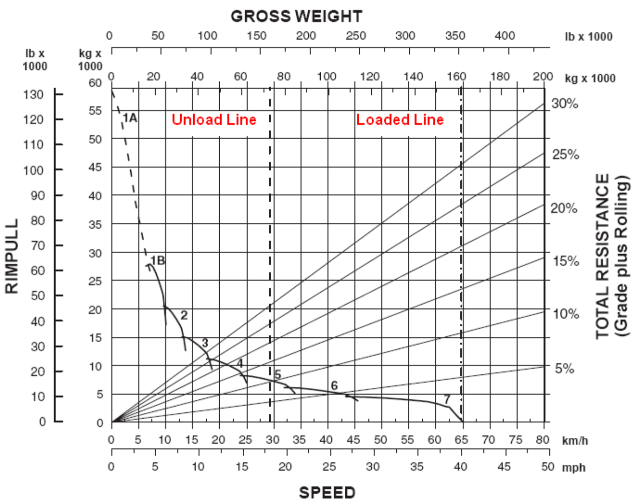
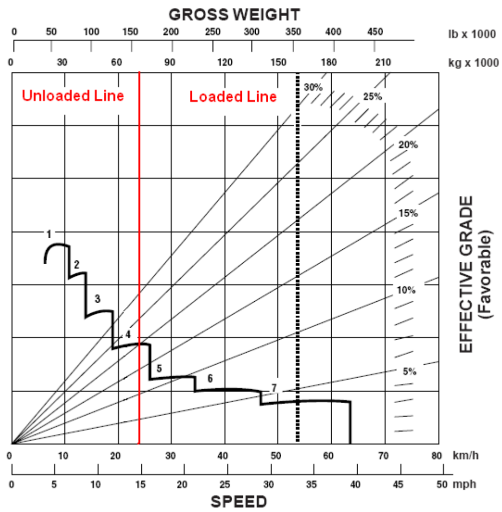


Figure 4 Caterpillar 777D truck performance graphs

Caterpillar 777D Rimpull-Speed-Gradeability



Caterpillar 777D Brake Performance
Continuous Grade Retarding



Electric trucks and trolley assist

The model will work for electric trucks and trolley assist applications but calibration of the transmission efficiency and retarder factors may be required.

Retarder options

Some trucks have additional retarder capacity options. In these cases the retarder factor would have to be increased.

Engine Load

The engine loading (up ramp) is calculated in Equation 3.

Equation 3: Engine loading

$$EngineLoading=\frac{UpRampTruckSpeed*TotalTruckWeight*9.81*(RampGrade+RollingResistance)}{3.6*GrossEnginePower*TransmissionEfficiency*(1+RampGrade*RampGrade)^{0.5}}$$

Fuel consumption

Fuel burn estimates are approximate (+/-10%) (refer Equation 4).

Equation 4: Fuel burns

FuelBurn=23.3%*GrossEnginePower*(EngineLoading*96%+4%)

The 23.3% factor seems to be a reasonable average estimate. If the maximum fuel burn is known for the truck type then the factor can be re-calculated (refer Equation 5).

Equation 5: Fuel burn factor

$$\text{FuelBurnFactor}=\frac{\text{MaximumFuelBurn}}{\text{GrossEnginePower}}$$

Practical Application

Table 1 contains the formulas previously discussed in a simple model for the Hitachi EH4500 truck. The key assumption is that the haulage profile segments can be re-calculated into an equivalent profile using level, up 10% or 10% down, segments. Real haulage profiles never meet this constraint but the error resulting from the assumption is not considered significant.

Table 1 The EH4500 truck performance model

EH4500	Level	Up Ramp	Down Ramp
Case			
Grade	0.0%	10.0%	-10.0%
Engine power (kw)	2,014	2,014	2,014
Transmission efficiency	80%	80%	80%
Retarder Efficiency	115%	115%	115%
Rolling resistance	2.5%	2.5%	2.5%
Loaded Performance			
Loaded weight	479	479	479
Loaded Speed Limit	45.0	30.0	30.0
Speed	45.0	9.9	23.8
Engine Power	91%	100%	0%
Fuel Consumption (ltr/hr)	429	469	14
Unloaded Performance			
Unloaded weight	211	211	211
Unloaded Speed Limit	45.0	30.0	30.0
Speed	45.0	22.5	30.0
Engine Power	40%	100%	0%
Fuel Consumption (ltr/hr)	197	469	14*

- Some truck manufacturers shut the injectors off when the truck is running down ramp
- The blue text are input values while the black text are calculated values

The unloaded weight is from the manufacturer's handbook but could be increased if necessary to allow for "carry-back" (that is material stuck to the truck tray).

Table 2 illustrates the extraction of the key data for truck modelling.

Table 2 Rationalised EH4500 truck performance

Truck Speeds (km/hr)		
	Loaded	Unloaded
Level	45	45
Up Ramp	9.9	22
Down Ramp	24	30
Truck Fuel Burns (l/hr)		
	Loaded	Unloaded
Level	429	197
Up Ramp	469	469
Down Ramp	14	14
Idle	14	14

Table 3 Schedule truck capacity, effective operating time and cycle delays

Truck Schedule Data	
Unloaded Truck Weight	198
Maximum Truck Weight	480
Carry Back	5%
Nominal Capacity	100%
Moisture (%)	4%
Capacity (dmt)	257
Productive Hours per Year	6,600
Effective Minutes per Hour	50.0
Queue & Spot	1.0
Load	2.5
Dump	1.0

Table 4 presents an example haulage profile.

Table 4 Haul profile

Haul Distances	
Forward Trip (Loaded):	
Level	800
Up Ramp	1,800
Down Ramp	300
Return Trip (Unloaded):	
Dump	
Up Ramp	300
Down Ramp	1,800
Level	800
Total Metres	**5,800**

Using the truck speeds from Table 2 and haul distances from Table 4, the cycle time can be calculated (refer Table 5).

Table 5 Cycle times

Cycle Time	
Forward Trip (Loaded):	
Queue & Spot	1.00
Load	2.50
Level	1.07
Up Ramp	10.90
Down Ramp	0.76
Return Trip (Unloaded):	
Dump	1.00
Up Ramp	0.75
Down Ramp	3.60
Level	1.07
Cycle Time	**21.68**

Using the truck fuel burns from Table 2 and cycle time components from Table 5 the fuel burns can be calculated (refer Table 6). The fuel burn per effective hour (50 minute hour) is the fuel burn per cycle multiplied by the cycle time.

Table 6 Fuel burns

Truck Cycle Time and Fuel Burn Calculations	
Fuel Burn	
Forward Trip (Loaded):	
Queue & Spot	0.23
Load	0.59
Level	7.63
Up Ramp	85.15
Down Ramp	0.18
Return Trip (Unloaded):	
Dump	7.82
Up Ramp	6.26
Down Ramp	0.84
Level	3.51
Litres/Cycle	**104.4**
Litres/Effective Hour	**288.9**

Table 7 presents the final truck productivity and fuel burn per productive hour.

Table 7 Final Truck productivity and fuel burns

Truck Cycle Time and Fuel Burn Calculations	
Truck productivity (tonnes) per Productive Hour	**626**
Truck Fuel Burn (kilolitres) per Productive Hour	**229**
Truck productivity (tonnes) per Year	**4,131,293**

Sensitivities

For the practical example above, a 2.5% rolling resistance was applied. This value is suitable for good road conditions. What would happen if the rolling resistance was 3% and the maximum level speed reduced to 30km/hr (from 45km/hr)? The model (refer Table 8) suggests that productivity would fall about 7% (or haulage costs would rise about 7%).

Table 8 Truck productivity for 3% rolling resistance and a 30km/hr speed limit

Truck Cycle Time and Fuel Burn Calculations	
Truck productivity (tonnes) per Productive Hour	**593**
Truck Fuel Burn (kilolitres) per Productive Hour	**243**
Truck productivity (tonnes) per Year	**3,912,381**

Conclusion

The modelling of truck performance directly in a spreadsheet is not particularly difficult and allows tighter integration of the schedule and cost model. Useful for "what if" scenarios as demonstrated above.

If you would like a copy of the spreadsheet used above, please email: **acooper@snowdengroup.com**.