SCHOOL OF MATERIALS AND MINERAL RESOURCES ENGINEERING

UNIVERSITI SAINS MALAYSIA

CYCLE TIME OPTIMIZATION ON IMERYS USING TALPAC

By

MUHAMMAD AZLI AZAM BIN BASIRUM

Supervisor: Dr.Teuku Andika Rama Putra

Dissertation submitted in partial fulfillment

of the requirements for the degree of Bachelor of Engineering with Honours

(Mineral Resources Engineering)

Universiti Sains Malaysia

JULY 2017

DECLARATION

I hereby declare that I have conducted, completed the research work and written the dissertation entitled: "**Cycle Time Optimization on Imerys using Talpac**". I also declare that it has not been previously submitted for the award of any degree or diploma or other similar title of this for any other examining body or university.

Name of student   :Muhammad Azli Azam Bin Basirum   Signature:

Date   : 3 July 2017

Witness by

Supervisor   :Dr. Teuku Andika Rama Putra   Signature:

Date   : 3 July 2017

ACKNOWLEDGEMENTS

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LIST OF ABBREVIATIONS

FPC   Fleet production and Cost

IWH   Idling Working Hours

OEE   Overall Equipment Effectiveness

RPM   Rotational per Minute

TKPH   Tonne kilometres per hour

TPH   Tonne per Hour

TPMS   Truck Payload Management System

TPD   Tonne per day

LIST OF SYMBOLS

Km/h   Kilometre per hour

m^3/h Cubic metre per hour

min   Minutes

%   Percentage

t/hr   Tonne per hour

m   Metre

KITARAN MASA OPTIMUM DI IMERYS MENGGUNAKAN PERISIAN TALPAC

ABSTRAK

Industri perlombongan dan kuari telah dikelaskan sebagai salah satu sektor ekonomi yang besar di Malaysia. Sektor ekonomi ini semakin meningkat dari tahun ke tahun menurut Bank Negara Malaysia. Hasilnya ialah peningkatan permintaan daripada industri-industri lain yang memerlukan industri perlombongan dan kuari bekerjasama menghadapi keadaan ini dengan menghasilkan produk dengan lebih efisien. Daripada kajian ini, pengeluaran tan setahun dapat ditingkatkan jika pengangkutan itu beroperasi dengan cekap. Faktor lain juga memberi kesan kepada produktiviti operasi kuari seperti mesin pengorek tanah, jalan, dan kecekapan operator. Kajian membuktikan bahawa penilaian bebas bagi setiap kombinasi adalah perlu untuk mengenal pasti gabungan optimum. Mesin pengorek tanah yang lebih besar boleh menyebabkan kos perlombongan yang lebih rendah dengan mengurangkan tempoh sistem operasi. Tambahan pula, masa kitaran optimum tanpa mengabaikan keselamatan pengendali dan peralatan telah dikaji dan dianggarkan. Perisian simulasi seperti perisian Talpac adalah salah satu perisian yang menganggarkan masa kitaran dan pengeluran setiap jam operasi berdasarkan kajian kes sebenar. Anggaran adalah untuk mencapai parameter baru dan masa kitaran yang optimum.

CYCLE TIME OPTIMIZATION ON IMERYS USING TALPAC SOFTWARE

ABSTRACT

Mining and quarrying are classified as one of the major economic sectors in Malaysia. This economy sectors are increasing year by year recording to Bank Negara Malaysia. The result is increasing demand from other industries that need quarry and mining to cope with the situation to produce materials efficiently. From this study, the production of tonnage per year can be increased if the haulage are operates efficiently. Other factor also affect the productivity of the quarry operation such as excavator, haul road and operator efficiency. Study proven that independent evaluation of every excavator-truck combination is necessary to identify the optimal combination. Larger excavators may result in a lower mining cost by reducing the system operating duration. Furthermore, the optimum cycle time without neglecting safety of the operators and equipment was studied and estimated. Simulation software such as Talpac software is one of the software that estimate the cycle time and production per operating hour based on the real case study. The estimation resulted is to achieve new parameters and optimum cycle time.

CHAPTER 1

INTRODUCTION

1.1 Background

The use of simulation became increasingly of availability and affordability of personal computing during 1980's. One of the application of this new tool was the classic earthmoving problem involving selecting the number of trucks and excavators for a given mass haul. My final year project are related to the simulation that is Talpac software that supervised by Dr Teuku Andika Rama Putra.

Cycle time can be define as the complete period required to complete one cycle of an operation that include loading, hauling, unloading and lastly loading point. The perfect cycle time can differentiate whether the complete operation is efficient or vice versa.

In the mining sector, simulation replaced the role of manual calculation to solve optimization problems on various system and study various issues such as fleet requirement, the flow of hauling machines, and mine planning. Simulation for example Talpac software enables analysis, understanding, and hence improvement and optimization of existing and future system(Gransberg, 1996).

In fact, in order to achieve monthly and annual target for the quarry company is the critical aspect in the quarry industry. The higher production than monthly and annual target has to be achieve then the profit of the company can be increased.

1.2 Problem statement

All the parameter needs to be observed first before the evaluation been done. Demand from industry are increasing year by year. To cope with this situation, efficiency and productivity of an operation need to be increase without neglecting safety aspect. As to increase efficiency, there are multivariable factors need to be dealt with such as road condition, operator behaviour, articulated dump truck, weather, and loader capability.

These factors may affect the efficiency of the cycle time in the operation. Furthermore, correct cycle time can reduced the cost, time and can prevent wastage of resources on running the machine.

Besides, the developed optimization models are site oriented and shall not be simply adopted by other side. The variation in geologic, climate, human related, and various other factors can reduce the accuracy of the model on other location.

Furthermore, changes in haul road distance and dump location may change the result of the cycle time optimization on Imerys Mineral Malaysia Sdn Bhd. On the other side, safety measures also plays an important role to have an increment in productivity.

1.3 Research Objectives

   I.   To determine and compare various parameters that will affect to the cycle time optimization on Imerys.

  II.   To evaluate the compatibility and efficient of the Talpac software.

 III.   To evaluate the limitation of the present equipment scheduling optimization approach compare to previous equipment.

1.4 Scope of research work

In the end of this thesis, it will study on the limit to optimization of loading and haulage operation, which included the optimization of excavator-truck, truck fleet scheduling, and minimization of operating cost. Furthermore, this thesis also show the use of Talpac software on calculating the cycle time optimization on Imerys whether it suitable or not. Lastly, various recommendation needs to be made in order to reduce source of errors or problem that are related and a conclusion regarding the productivity after efficiency due to cycle time analysis has been improved.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Inherent to the investigation of the manufacturing cycle time is a set of activities, from defining the optimum production lot, calculations of the quantity of required parts, production preparation and launching, cycle scheduling, management of production activities with current asset engagement, to the analysis and investigation of material flow (Ernest and Young, 2014). Nowadays, in mining industry global competitiveness is leading towards maximizing productivity by controlling capital and operating cost(Singh and Narendrula, 2006).

The software that been used to calculate cycle time is Talpac software where some information measure has to be taken in order to complete the cycle time. The information that will be use such as the material that has at the Imerys quarry, the roster for the workers, the haul cycle for the articulated dump truck from loading to unloading, the type of articulated dump truck that use and lastly the type of excavator that been use. These measure needed in order to complete my thesis on cycle time optimization on Imerys using Talpac software.

The production cycle employs unit operations that are normally grouped into rock breakage and material handling. The breakage usually consists of drilling and blasting and after that follow by haulage and hoisting. Good drilling and blasting will determine the good of rock fragmentation and then the next process will be easy due to the size of the rock smaller that will feed into the jaw crusher at the Imerys quarry.

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Production cycle = Drill + Blast + Load + Haul

The production cycle mainly consist of the equation above and most of the quarry in the Malaysia employ excavator-truck system. This system is more or less capital cost and higher flexibility in loading and dumping spot compared to the other system such as conveyor belt and railway system. Proper fleet of trucks and loaders must be selected to ensure the operation proceeding at minimal expenses(Lai, 2009).

For the new frontier in quarry transport, there are a few equipment selection criteria that are be listed from Institution of Engineers (IEM) (Eric Goh, Chen Nyet Lin, et al. 2010) such as

- Site requirement
  - Presence of multiple loading faces, blending requirement, loading area support equipment needs and blasting restrictions
- Quarry bench / face setup
  - Material angle of repose, bench/ face height and angle, bench width and manoeuvring space and work condition of floor
- Material characteristics
  - Type of bench/ face material and level of material fragmentation
- Equipment performance
  - Productivity (tonnes/day), cycle time/speed, and power required and reliability
- Equipment design
  - Quality, efficiency, competency of operator and control system setup
- Effectiveness of maintenance setup

➤ Quality of service, ready availability of space parts, and level of competency of technical team

- Economic cost factors

    ➤ Capital, operating, duel costs, maintenance, spare parts, and expected salaries of skilled operations.

Table 2.1: The selection guidelines for material handling in quarry (surface mining) (Hartman, 2002)

Criteria	Excavator-truck	Wheel excavator-conveyor
Maximum production	High	High
Production rate	High	High
Pit life	Medium	Long
Pit depth	Deep	Medium
Deposit	Consolidated	Uniform, no large boulders
Preparation(if required)	Drill and Blast	Drill and blast
System complexity	Medium	High
Operational flexibility	High	Low
Blending capability	Medium	Low
Selective placement(disposal)	Good	Medium
Wet weather impact	Medium	Low
Scheduling requirement	High	Medium
System availability	Medium	Low
Support equipment	Medium	High
Ease of start-up	Simple	Complex
Investment	Medium	High

Table 2.1 shows the differences between excavator-truck and wheel excavator-conveyor. There are different such as pit life, pit depth, deposit, and etc. The most important criteria and target that quarry company want is for high maximum production with the lower operating cost or investment. From the table above, it is clearly shows that the excavator-truck is better system than wheel excavator-conveyor.

2.2 Parameter of Talpac

2.2.1   Material characteristics

Material characteristics needs to be decide before choose the suitable haulage system for the operation of the quarry. This parameter is important to calculate the cycle time due to it is include in the truck-excavator system where each material needs to be handle differently. The material loose density and bucket fill factor for the selected material should be known prior to equipment selection. These two factors can be obtain by physical test on rock in the laboratory. However, if the result are not available, the result can be obtain by refer to the table that contain the information of fill factor of each material. Each material have different fill factor range that needs to observe and if not, it will affect the cycle time optimization of the quarry operation. Poor loader bucket fill factor leads to the decreased of the heaped bucket capacity.

Table 2.2: Fill factor range (percent of heaped bucket capacity (Caterpillar, 2015)

Material	Fill factor range (percent of heaped bucket capacity)
Moist loam or Sandy Clay	100-110%
Sand and gravel	95-110%
Hard, Tough clay	80-90%
Rock-well blasted	60-75%
Rock-poorly blasted	40-50%

2.2.2 Roster

This factor is important to schedule the roster for the worker. It means the perfect roster will leads to organize working timetable and increased the operator productivity. For a piece of equipment, operator productivity greatly affects the actual production during the Idling Working Hours (IWHs). The operator productivity in terms of the moved volume of earth per operator hour and the number of work cycles completed per operator minute is discussed. Furthermore, poor operator performance is indicated by a high PAR value. Poor operator can cause the operation of the quarry become slower and inefficiency. Each operator also have their own skills whether handling the trucks and excavator or other work. Pushing the limit of the operator will causes the exhaustion of operators, and hence reduce their working efficiency.

2.2.3 Haul cycle

This factor is needed to decide whether the road or haul cycle is suitable for the operation of the quarry or not. Haul cycle can also be known as site condition where it will influence the truck cycle time. The measure that need to be take care such as production requirement and operating schedule, material characteristics, physical and climate condition, road characteristics, loading and dumping location. If these measure do not observed, the effects will lower down the working performance. The haul cycle in the quarry may change over time but the changes need to be control in order to obtain working efficiency. Poor haul road and climate will negatively affect the articulated dump truck to move from loading point to the unloading point. It will also cause the reducing travelling speed for the articulated dump truck and time travel for the cycle time will increased (Krzyzanowska, 2007).

2.2.4 Loading unit

In any operation, the equipment that important in the operation of the quarry is the excavator that function as to load the material into the articulated dump truck. Each excavator that have different brands have their own advantages and disadvantages. Furthermore, each excavator have their own capability which means the bucket capacity, the angle of turn and its efficiency. The hourly production for each model of excavator can be calculate using this following formula (Caterpillar Inc, October)

$P_{(UNIT)} = 60/BCT \times BC \times D_{MAT} \times BFF \times MA \times JF$

Where:

- P_{UNIT} = Excavator productivity(tph)
- BCT = Bucket cyclic time (min)
- BC = Bucket capacity (m^3)
- D_{MAT} = Material density (t/m^3)
- BFF = Bucket fill factor
- MA = Machine availability
- JF = Job factor

The amount of the excavator can increase optimization of equipment, profitability can be raised. But if the amount of the excavator exceeds the needed, it will less profitability for the quarry operation. Time taken to spot and load, haul, dump, and return needs to be considered when calculating cycle time for a truck. The excavator driver also need to be alert if the ore is waste ore or production ore. The bucket cyclic time is generally proportional to bucket capacity (Ercelebi and Bascetin, 2009).

The number of excavator can be calculated by using equation:

$$N_{EX} = P_{TARGET} / (P_{UNIT} \times HOUR_{MAX})$$

Where:

- N_{EX} = Number excavator required

- P_{TARGET} = Target production (tpd)

- P_{UNIT} = Unit excavator productivity (tph)

- $HOUR_{MAX}$ = Maximum daily operating hour (hr/day)

Excavator also need to consider the fuel consumption when operating the machine. So that each excavator that have different brand have their own tank that control fuel consumption. Excavator operators therefore have a dual challenge, firstly to lower fuel consumption in order to reduce cost, but without compromising machine productivity (m^3 /h), and secondly, to reduce fuel consumption.

Fuel consumptions of a the RPM setting is the greater the amount of fuel that will consumed given that at a particular period, a certain amount of fuel is injected into the combustion chamber for combustion. Whereas, task efficiency is the measure of input required to achieve a particular amount of output (Klanfar, Korman et. al, 2016).

A machine mode is designed to deal with the challenges to gives customer and machine greater flexibility which commonly performing various tasks such as reducing fuel consumptions, save time, or breaking through hard materials. The effects of bucket capacity is also commonly considered such as dig depth, slew angles, bucket capacity and machine weight and used data from construction site.

Usually excavator have two main sections that is undercarriage and the house.

- Undercarriages : Includes the blades, tracks, track frame, and final drives, which have a hydraulic and gearing providing the drive to the individual tracks

- House: Includes the operator cab, counterweight, engine, fuel and hydraulic oil tanks.

Engines in hydraulic excavator usually have 3 pumps that is:

1. Two main pumps : supplying oil at high pressure (up to 35000 kPa) for the arm, swing motor, track motors, and accessories

2. One pumps : lower pressure (5000kPa) pump for pilot control, this circuit used for the control of the spool valves
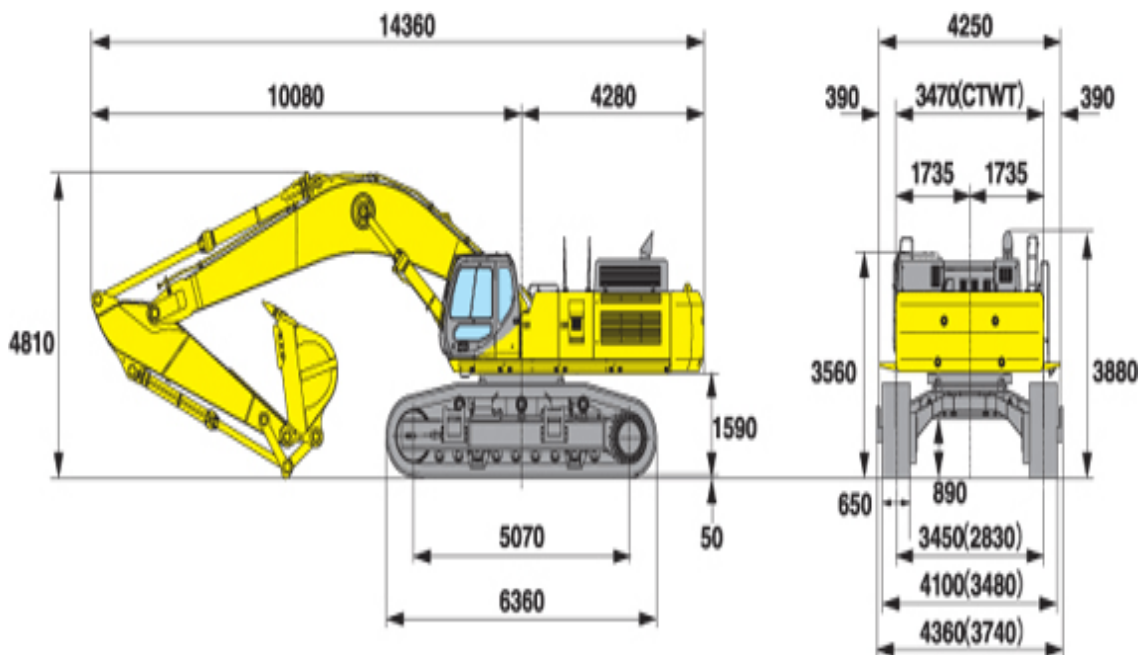
Figure 2.1: Dimension length of the Volvo A40F (Haulers, 2005)

To increase productivity, truck-loader cycle optimization are commonly performed. The overall equipment effectiveness (OEE) techniques are needed to apply in the quarry operation. It will combines availability, performance and quality, for the evaluation of equipment effectiveness in manufacturing industry. This can improve profitability of the mobile assets at the mine and hence reduce cost.

With OEE, it can detect time losses for loader and truck operations and introduces the procedure to record that time. The simulation software such as (TALPAC, FPC etc.) can calculate the overall productivity of the operations. Major factors for truck-loader productivity (Choudhary, 2015):

- Truck-shovel match

- Truck shovel allocation

- Inefficiencies in drilling and blasting

- Truck size and spotting time

- Haul road and ramp design, resistance

- Operating schedule and efficiency

$$\text{Productivity} = \frac{production}{operating\ time}$$

Good operational of the quarry can give many benefit to the quarry company especially to the operating cost and profitability. In order to achieve that, some operational characteristics can be observed:

- Excessive truck queuing times at the loading unit

- Excessive loader wait on truck

- Abnormal queue time at the dump

- Truck bunching (typically observed during with fleet haulage)

Total truck cycle time = Loading time + hauling time + dumping time + return time + spotting time (Andika, 2014)

$$\text{Loader productivity} = \frac{(loader\ capacity)(loader\ efficiency)}{(loader\ cycle\ time)} \qquad \text{Eq. 2.1}$$

$$\text{Truck productivity} = \frac{(truck\ capacity)(number\ of\ trucks)}{(truck\ cycle\ time)} \qquad \text{Eq. 2.2}$$

$$\text{Number of trucks, } M_b = \frac{(loader\ productivity)}{(truck\ productivity)} \qquad \text{Eq. 2.3}$$

$$\text{Match factor, MF} = \frac{(number\ of\ trucks)(loader\ cycle\ time)}{(number\ of\ loaders)(truck\ cycle\ time)} \qquad \text{Eq. 2.4}$$

As it can be used to match truck arrival rate to excavator arrival rate, it is so called as match factor. As match factor between truck and shovel can be built, so estimation of cycle time can be determine. This equation as roughly estimation due to it is not calculate by software that is more accurate. Inefficient cycle time lead to the higher cost production, and more time needed for the operation. For maximum efficiency, fill trucks as close to their rated hauling capacity as practical (Vemba, 2004). Overloading the material into the trucks will cause higher fuel consumption, reduced tyre life, and increased mechanical failures. So, excavator driver need to expertise to load the material into the articulated dump truck as 10-50 tan in Malaysia. In specific, truck load time is normally considered to include manoeuvring at the load area, queuing, and the actual loading time. The matching of loading and hauling equipment is a most vital consideration in selecting a truck fleet (Torino, 2016).

Each changes and decision that make will cause an advantages or disadvantages. For example, if there are too few loaders then the truck will queuing to take turn for the loading the material to the truck. While, if there are too many of the loaders, the cost to buy and maintenance the machine will be also higher. Most operator consider the optimum loader size to be that requiring four to six passes to fill the truck. The skills of the articulated dump truck driver to handle the truck effectively can change the cycle time to become more efficient.
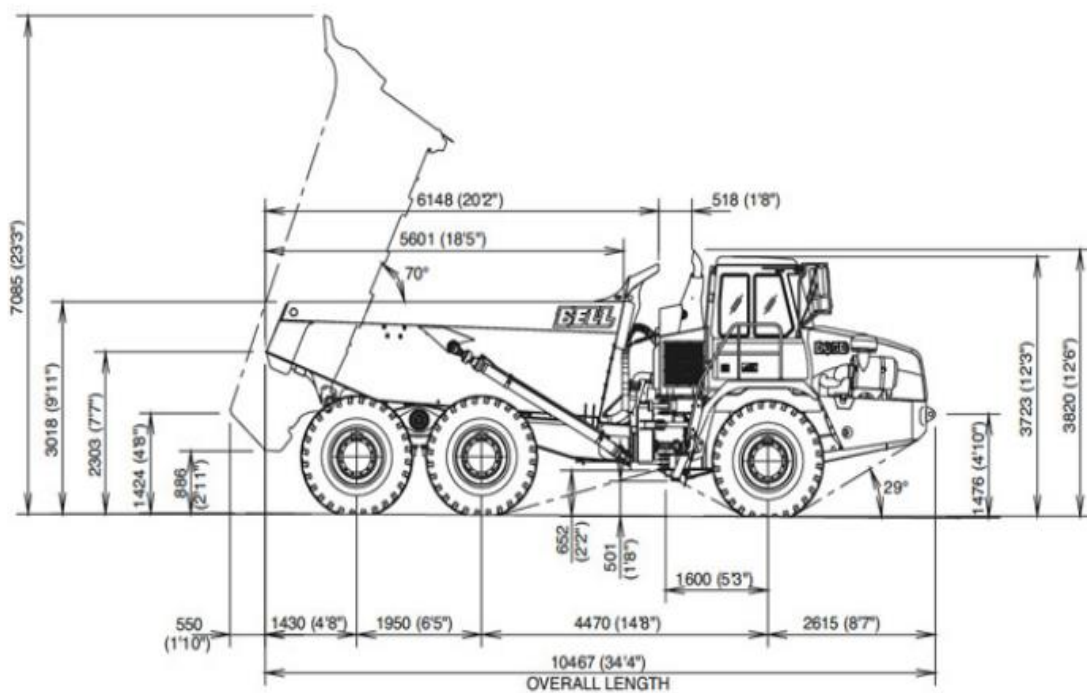

Figure 2.2: Example drawing for the articulated dump truck (Hall, 2010).

2.3 Safety

Safety must been developed in order to make the working place is safe for the operator and others. Safety include all aspect of the working area that has the OSHA rule. In order to reduce operation cost and increase productivity, mining machine is becoming larger to cope with the production. As an example, the truck also have their safety that need to be observe such as their engine, operator and tyres. As the economy drop, many quarry company decide to go buy tyres from the lower aspect of safety that means the lifetime of the tyres is short, tyre performance is decreased and operating cost also lower. With rapid development and massive construction in some Asia countries such as China and India, demand for raw materials has boosted and prices for most commodities are going up continuously. To grab this economic chance, many mine are reopen yet the mobile performance characteristics are limited with matching tire capabilities.

Furthermore, the safety measure is less been took care from quarry company. This is because some of the quarry company that safety is more costly to be take care. Some opinion that safety is troublesome to complete the work. For optimization and safety purpose, tire rotation practice is applied. The goals of tire rotation are:

- For safety, front tires support the drivers cab
- For tire matching ; 10mm tread depth difference need to be rematches
- For even tire load and air pressure
- For reducing tire failures and extending tire life

2.4 Simulations

Talpac is one of the simulations that are commonly used to calculate the cycle time in Australian mining (Emmanuel K.C, 2010). Other software that use the same concept like Talpac is Fleet Production and Cost software (FPC) by Caterpillar(Doig and Kizil, 2013). These such software is to determine the truck-loader fleet productivity expressed in Bank Cubic Meter (BCM) per operating hours. Other calculations by using equation can also be use but in order to save time and get the accurate result this software is needed.

The key factors that need to be observed such as:

- Material

- Roster

- Haul cycle

- Loading unit-excavator

- Truck

Moreover, the measure that need to be include is cost data which include the fuel for the operating hours, bucket capacity for different material, nominal truck capacity and others. For the truck-shovel the key factors such as fleet size, motor power, transmission speed, truck payload, rolling resistance, and traction coefficient for the optimization.

Moreover, Talpac has been programmed to calculate the cycle time efficiently. For example, Talpac estimates the number of trucks required to keep the loader busy as follows:

$$\text{Estimated Fleet Size} = \frac{Truck\ cycle\ time\ for\ actaul\ truck\ payload}{(mean\ truck\ loading\ time + truck\ spot\ time\ at\ loader)} \qquad \text{Eq. 2.5}$$

Talpac can calculating and reporting fleet productivity in proper form so that it can interpret into the graph as shown below:
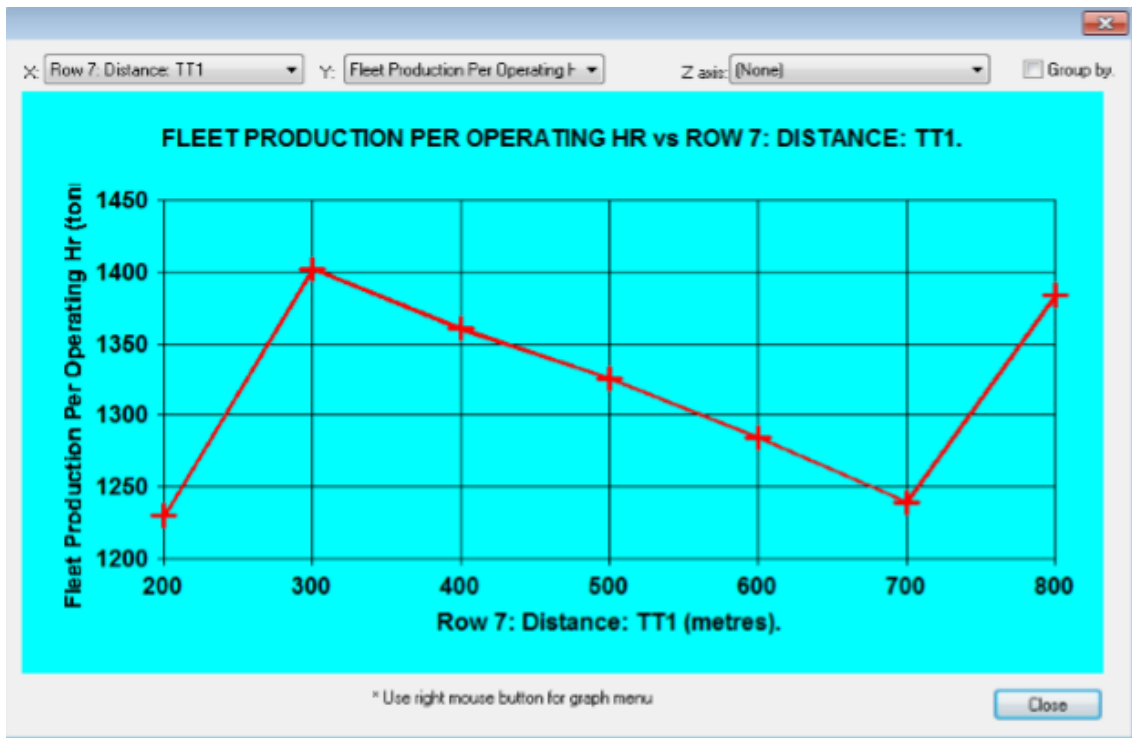
Figure 2.3: Example graph simulation by Talpac
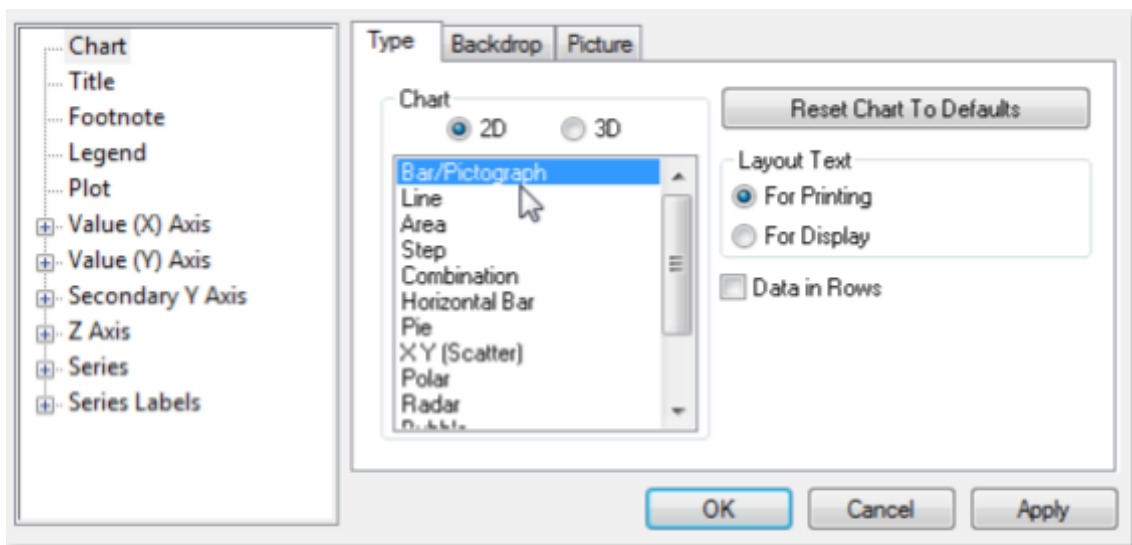
Figure 2.4: Example various graph that Talpac can create for simulation

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The advantages of the Talpac not only it save time but this software also can determine fleet comparison by created a new haulage system that is going to be configured for the larger equipment. New truck and loader templates will be created.

Table 2.3: The specification of Komatsu shovel and truck

Description	Shovel	Truck
Name	Komatsu PC3000-6	Komatsu HD1500-7 (Cont Retard)
Type	Hydraulic Shovel	Rear Dump Trucks
Capacity	16.0 cu.m heaped	144.2 tonne payload
Availability	90%	85%
Capital Cost	$2 000 000	$1 300 000
Residual Value	10%	10%
Life in Hours	35000	35000
Life in Years	8	8
Depreciation type	Straight line	Straight line
Depreciation Rate	15%	25%
Total Operating Cost	$222.73	$163.50

CHAPTER 3

METHODOLOGY

3.1 Flow diagram of research

The flow diagram is needed to make the process and work become easier. Furthermore, the flow diagram can identify the problem from step by step. The flow diagram of research as shown in figure 3.1.
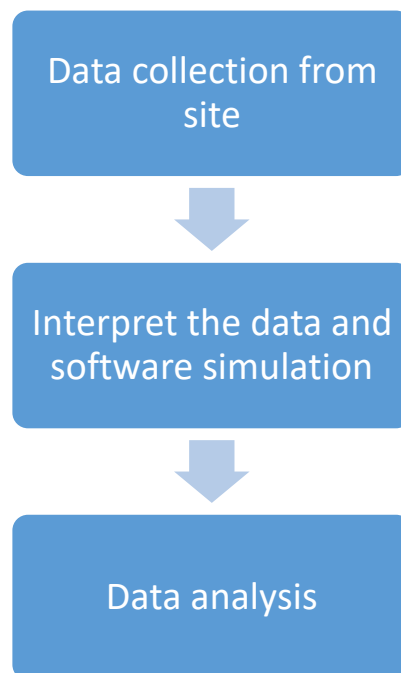
Figure 3.1: Flow diagram of research

3.2 Data collection from site

Based on Figure 3.1, the figure shows the process of how this research were conducted. Mainly this research is done by observations of the process in the quarry. The observations are carried out on the site in which the site should be observed properly and identify the problem. Other reasons is to obtain manual records of cycle time in a more systematic ways in order to get the accurate result. Moreover, the reality situation in the quarry provides the problem that the operator was handled and also other factors that can minimise the efficiency of the cycle time in the quarry (Chanda and Gardiner, 2010).

3.2.1   Field data collecting

The quarry site in the Imerys is called as Zain Liew quarry where it is the second quarry after the first quarry that is Honaik quarry. The site was been extracting and the process could been done such as blasting, hauling, and crushing. The blasting process would usually done by afternoon so the quarry must be stop for an hour for the complete blasting and for the safety measures.

While for the hauling process, the time must be taken by using stopwatch and record it in the logbook. The data recorded at the point where the truck hauling and go down for the dumping or crushing. The other point is where the excavators hauling the material into the trucks that include the time to select the good sell product or waste product. The good sell product will directly into the crusher and undergo the next process but for the waste product, the material will dump at the waste area.

The time for the excavator recorded when the moment the excavators digging time, swinging time, material selection and full hauling to the articulated dump truck. The efficiency of the excavator will leads to the less time and more production will produced. As for the loading unit template, there are some measures that need to be observed such as database bucket capacity, available bucket capacity (Fill factor applied), actual bucket capacity, and bucket cycle time. Haul road conditions also effecting the efficiency of the cycle time where if good haul road condition will lead to the higher production to sell to the buyers such as Japan, Vietnam and other country.

Figure 3.2: Excavator are loading the material into the truck bucket

Figure 3.3: Waste hard rock (limestone)

3.2.2 The input that are available

Example of the input that needed to complete survey in the Talpac software such as:

- Truck mechanical availability: 85%

- Loader mechanical availability: 78%

- The roaster used in the Imerys are 7 days and 12 hours working time. Scheduled lost shifts are the public holidays that are on the Malaysia calendar

- Average bucket fill factor: 1.24 fill factor

- Operators efficiency: 67% and 75% and usually articulated dump truck driver will make 17 to 19 trip per day

- Operating cost for the excavator and articulated dump truck

- The various possible routes that are extracted from SURPAC software where being simulated in the Talpac software and the data will be analyse to determine the cycle time optimization on the Imerys

For the roasters, there are some availability that is made up of:

$$Availabilty = \frac{time\ operated}{time\ operated + maintenance\ down\ time} \qquad \text{Eq. 2.6}$$

Maintenance downtime is made up of work and no work. The description is below:

Example work:

- Inspections- scheduled routine inspections/ adjustments

- Servicing- scheduled routine services such as hours and time based

- Modifications- job request and analysis of equipment failure history

- Unscheduled repairs- breakdowns

- Lubrication- scheduled lubrication

- Conditions monitor-scheduled sampling and scheduled measurement

- Testing- scheduled testing and statutory testing

Example no work because of delays with:

- Parts- warranty, incorrect item, wait for purchase, out of stock, substandard, issue delays, and others

- Labour- availability not enough, industrial, and safety

- Facilities- workshop space, workshop access, services, special tools, transport and work environment

- Setup- machine/equipment accessibility, machine/equipment positioning and others

- Environment- weather, dust /noise pollutions and others

Table 3.1: Example of calendar hours

Calendar hours					
Scheduled hours					Unscheduled hours
Available hours					
Operating hours		Stanby hours	Maintenance hours		
Work hours	Delay hours		Planned	Unplanned	
Basics functions	Fuel and services	Industrial delays	Periodic and condition based repair time	Corrective repair following breakdown	weekends or equivalent mine sgutdown or public holidays
Loading	Wait on excavator	Weather delays			
Hauling	Wait on equipment	No operators			
Dumping	Wait on blast	Training			
Floor cleanup		Meal break			
Minor inspections		Shift change			
		Preshift service			

3.3 Interpret the data and software simulations

3.3.1 Manual calculation for truck productivity

Formula for calculate truck productivity is shown as below by (Alan K. Burton, 1975)

$$Tons\ per\ truck\ hour \qquad\qquad\qquad Eq.\ 2.7$$

$$= \frac{60\ min\ X\ productivity\ factor}{theoretical\ cycle\ time\ min} x\ effective\ payload$$

$$Number\ of\ operating\ trucks \qquad\qquad\qquad Eq.\ 2.8$$

$$= \frac{hourly\ tonnage\ required}{tons\ per\ truck\ hour}$$

3.3.2 Manual calculation for excavator productivity

Based on formula below, the number of truck can be determine with different parameter in order to achieve the target of production.

$$\frac{Tons}{cycle} = \frac{Bucket\ capacity(m3)\ X\ Fill\ factor\ X\ density}{swell\ factor} \qquad\qquad Eq.\ 2.9$$