Simulation Model for Outbound Logistics in Quarry Business

Miss Chanyakan Chawaranggoon

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By	Miss Chanyakan Chawaranggoon
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Thesis Advisor	Associate Professor Wipawee Tharmmaphornphilas, Ph.D.

Accepted by the Faculty of Engineering, Chulalongkorn University in Partial Fulfillment of the Requirement for the Master of Engineering

.... Dean of the Faculty of Engineering

(Associate Professor Supot Teachavorasinskun, Ph.D.)

THESIS COMMITTEE

.... Chairman

(Assistant Professor Daricha Sutivong, Ph.D.)

.... Thesis Advisor

(Associate Professor Wipawee Tharmmaphornphilas, Ph.D.)

.... Examiner

(Assistant Professor Pisit Jarumaneeroj, Ph.D.)

.... External Examiner

(Assistant Professor Nantachai Kantanantha, Ph.D.)

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งานวิจัยนี้ศึกษาเกี่ยวกับโลจิสติกส์ขาออกในธุรกิจเหมืองหิน ซึ่งเป็นกระบวนขนส่งสินค้าประเภทหินก่อสร้างให้แก่รถบรรทุกลูกค้า กิจกรรมต่าง ๆ รวมตั้งแต่กิจกรรมแรกที่รถลูกค้าเข้ามาชั่งน้ำหนักในระบบ จนกระทั่งรถลูกค้าชั่งออกจากระบบอีกครั้ง การเพิ่มขึ้นของจำนวนลูกค้าในพื้นที่ ๆ จำกัดของกิจการและทรัพยากรจำนวนจำกัด ส่งผลให้เกิดเวลาที่ลูกค้าใช้ในระบบที่ยาวนานขึ้น ซึ่งก่อให้เกิดคิวการรอที่นานมากขึ้น งานวิจัยนี้จึงตั้งเป้าหมายเพื่อจัดทำแบบจำลองสถานการณ์สำหรับโลจิสติกส์ขาออกในธุรกิจเหมืองหิน เพื่อศึกษานโยบายในการจัดคิวรถบรรทุกและนโยบายในการจัดคิวรถตักเพื่อช่วยลดเวลาที่ลูกค้าใช้ในระบบและเวลาที่รถตักวิ่งไปมาในระบบในหนึ่งเดือน โดยการเลือกนโยบายที่ถูกต้องนั้นยังช่วยให้ระบบสามารถรับลูกค้าจำนวนที่เพิ่มขึ้นโดยที่ยังคงใช้ทรัพยากรเดิมที่มีจำกัด จากการศึกษานี้พบว่านโยบาย *Combined* ซึ่งเป็นนโยบายผสมระหว่าง นโยบาย *Shortest Processing Time (SPT)* และนโยบาย *Shortest Travelling Time (STT)* เป็นนโยบายที่เหมาะสมที่สุด โดยนโยบายนี้ช่วยลดเวลาที่ลูกค้าใช้ในระบบลง 32.33% และยังช่วยลดเวลาที่รถตักวิ่งไปมาในหนึ่งเดือนในระบบลง 7.53% หลังจากที่งานวิจัยพบนโยบายที่เหมาะสมแล้ว งานวิจัยนี้ยังทำการศึกษาเพิ่มเติมเกี่ยวกับการวางแผนชั่วโมงการผลิตในกรณีทีจำนวนลูกค้าเพิ่มขึ้นกรณีต่าง ๆ จากการศึกษาพบว่าระบบปัจจุบันหลังจากทำการปรับใช้นโยบาย *Combined* แล้วนั้น จะมีเวลามากที่สุดต่อวันที่ระบบสามารถผลิตได้ต่อวันคือ 540 นาที และจำนวนลูกค้ามากที่สามารถรับได้คือ ระดับลูกค้าเพิ่มขึ้น 50%

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The study of outbound logistics is part of quarrying process where final products are being served to customers. It includes all activities begins from when a truck entering weight station to when the truck leaves the system after a final weighing. An increasing of customer demands within limited serving space and limited resources cause a higher total flow time customer spent in the system which also leads to longer queues. The study aims to simulate a current outbound logistics for a quarry business using ARENA simulation model and analyze truck queueing and loader scheduling policy that help reduce total flow time of truck and loader’s travel time. The right policy also allows the system to be able to serve higher number of incoming customers using the same available resources. The results found that the *Combined policy* of *Shortest Processing Time (SPT) policy* and *Shortest Travelling Time (STT) policy* is recommended since it helps reduce 32.33% of the total flow time and reduce 7.53% of the loader’s monthly traveling time. After the suggestion on implementing the *Combined policy*, the study further investigates different scenarios in the case of increasing number of customers to help the quarry with a future production planning. The result shows that 540 minutes is the maximum daily production run time and 50% increase in number of customers is a maximum number of customers for the current system could handle after the implementation of Combined policy.

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Chapter 1: Introduction

1.1 Background of the research

Quarry business is similar to mining business and has a strong bond to construction industry. University of Leicester, geology department, defines quarry as a place where materials are extracted from the surface of earth (Leicester 2018). These materials then gone through crushing and screening process until they become aggregate – a material that can be used in construction such as crushed rock, sand, fine dust etc. The main activity of quarries in this paper involves aggregate production and serving them into customer's trucks.

Since aggregates is considered materials for construction work, the more construction and infrastructure projects, the more demand for aggregates from quarry business. ASEAN trend has immensely affected the growing in public construction investments in Thailand. This case study is in Chiang Rai, Thailand which is one of the members of ASEAN Economic Community (AEC). Chiang Rai has been receiving a great impact from the open of AEC as it becomes a northern gate connects Thailand to its neighboring countries; hence, a lot of construction and infrastructure projects are blooming within the province.

The Bureau of the Budget announced that the budget of 2018 fiscal year assigned to Chiang Rai province is a total of 13.603 billion THB, in which 4.722 billion THB belongs to government construction projects within Chiang Rai (Budget 2017). A study done by Krungsri bank also forecasts that for the next two years, Thailand public construction business will grow on average of 8%-12% per year (Toomwongsa 2016). Future projects supported by the government will ensure a strong demand in aggregate market using in construction within area.

1.1.1 Quarrying Process background

Although this study only focuses on the operations of outbound logistics in the quarry, a basic knowledge of general quarrying process would still be beneficial to understand the system as a whole. Aggregate quarrying process is a multistage process starting from (1) extracting rocks from the designated open pit area, (2) transporting them to the feeder of quarry machine, (3) crushing and screen them into different sizes of aggregate products through quarry machine, and (4) loading final aggregate products to the customer's trucks. This study focuses on the stage 4 of quarrying processing, which is the outbound logistics part, in which aggregate products are served by company resources i.e. loader onto a customer's truck.

In this study, there are a total of seven final aggregate products that customer can purchase and that the percentage of production differs across products. Please note that the percentage of production in Table 1 cannot be adjusted accordingly. This means that it is impossible to increase a production of one product by reduce the production of another product. Table 1 shows the breakdown of production percentage of each aggregate product in the subjected quarry.

Table 1: Amount of production percentage

	Product 1	Product 2	Product 3	Product 4	Product 5	Product 6	Product 7
% Production	10%	28%	6%	28%	8%	10%	10%

1.1.2 Outbound logistics operations background

The outbound of logistics operations only covers the delivery process of final aggregate products to customer's truck. Each aggregate product locates at the end of each conveyor line in its temporary stockpile. In the current system, there is one loader machine responsible to fill up the truck, running across all products. In the current system, FIFO queue is used when loader calls for a customer truck to be served.

Figure 1 depicts the flow process starts from an empty truck entering the system to a full truck leaving the system. The flow begins when an empty truck enters the system, weighs itself on scale and contacts the admin at the sales office. It then proceeds to the waiting area around quarrying machine. Since there is one loader machine responsible to serve products, trucks have to wait until the loader is free to serve. Once the truck is filled with aggregate, it then heads back to the weigh station and reconfirms with the admin, before leaving the system.

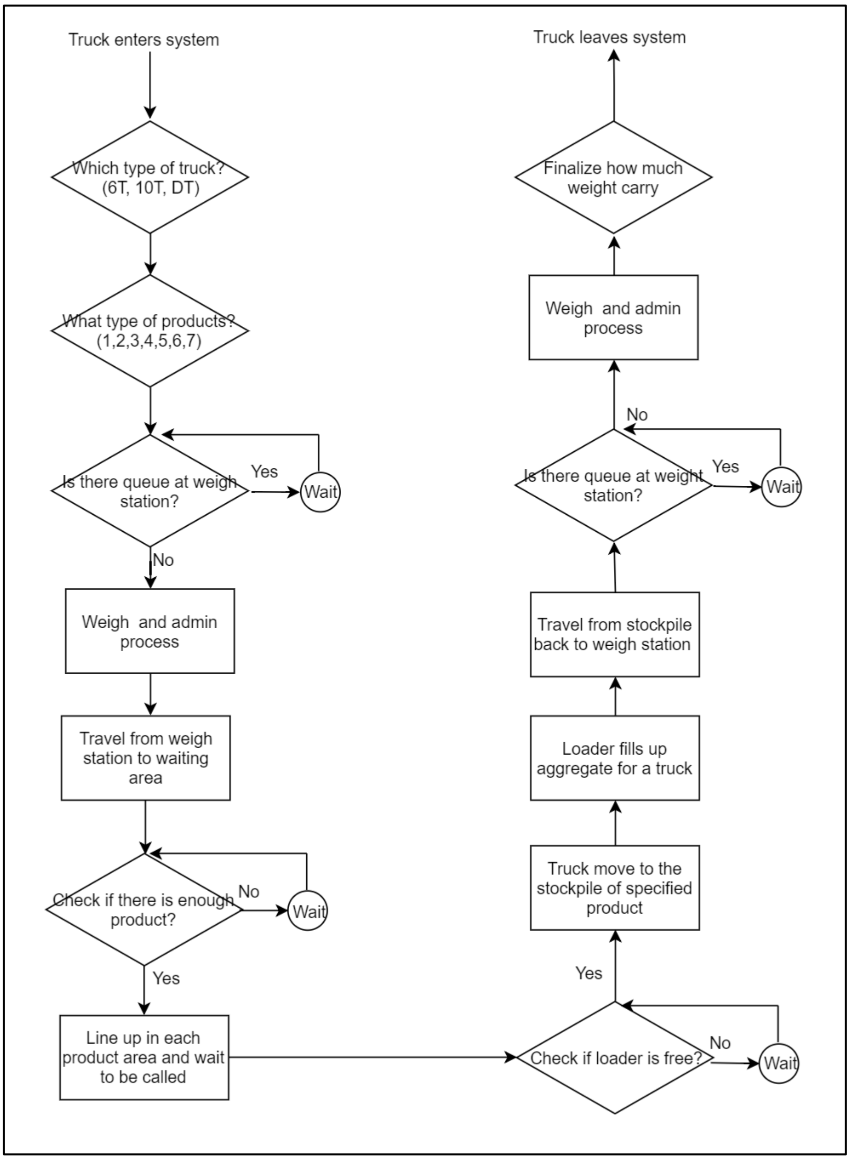

Figure 1: Flow chart of outbound logistics

1.2 Problem Statement

Although there are studies that focus on operations improvement in mining industry, most study focuses on either mining production planning or efficiency improvement of the inbound logistics operations from open-pit extraction to quarry machine. There is no study particularly focuses on the efficiency improvement on outbound logistics – transporting final aggregate products out to customers. With an increasing in customer demands in limited serving space, both outbound logistics and a queue issue raise a concern of the efficiency of the operation of the quarry as well as a customer total time spent in the system.

In this study, the model will be built based on the current state of the system using data collected in the month of May and June, 2018. There are three types of truck customers arrive based on hourly schedule which differs throughout the day on a weekly pattern; each customer with a probability of choosing one out of seven aggregate products. It is to be noted that with the nature of the outbound logistics in quarry business, all the incoming customers are served within that day; hence, due date will not be considered in the study and no customers are left within the system when the system shuts down. The production rate, although remains at constant rate throughout the production process, cannot be adjusted individually base on each product. This implies that it is impossible to increase a production of a certain product while reducing the production of the rest. This combination of customer arrivals based on schedule and how a quarry production line operates requires a need of using simulation model to analyze the current outbound logistics system and the problem of the queue. Hence, this paper focuses on reducing both average flow time as well as reducing loader's traveling time.

The decrement in both average flow time and loader's traveling time lead to a better operational efficiency in the outbound logistics of the quarry, which allows the system to be able to serves a higher number of incoming customers using the same available resources. Therefore, the study can help the quarry to be able to serve higher number of customers which align with the increasing trend in customer demands within Chiang Rai province.

In this paper, four policies including (1) Shortest Processing Time Policy (SPT), (2) Shortest Traveling Time Policy (STT), (3) Maximum Queue Number Policy (MaxQ), and (4) Combined Policy (SPT & STT) are presented to solve truck queuing and loader scheduling concerns. In addition to the suggestion to implement the best policy into the current system, the paper also wants to further explore and give recommendation on a production run time in a monthly time frame in different cases of increasing number of incoming customers. The paper is organized into the following chapters. Chapter 2 describes the literature review. Chapter 3 describes methodology of the study. Chapter 4 describes the experiments in four different policies which address truck queueing part and/or loader's scheduling part. The four policies include SPT policy, STT policy, MaxQ policy and Combined policy (SPT & STT policy). Once the best policy is recommended, the study further address the production planning for a future change in demand. Finally, Chapter 5 describes conclusion and suggestion from this study.

1.3 Objective

A large number of customer's truck leads to complications in managing the logistics process and affects limited serving space and safety. This paper aims to determine policies for truck queueing and loader scheduling that can help reduce both average flow time and loader's traveling time. An optimized alternative for truck queuing and loader scheduling policy can help improve the outbound logistics operation of quarry business. In addition to this, the study also aims to determine the appropriate daily production run time for the improved system in different scenarios in the case of an increase number in future demand. The study uses monthly production plan as a simulation time frame. The following summarizes the objectives of the study:

- Develop a simulation model that represents current outbound logistics system for quarry business
- Develop, analyze and test policies that help improve the operations in outbound logistics using the simulation model by reducing both average flow time and loader's traveling time.
- Determine appropriate daily production run time in different cases of an increase in number of incoming trucks for a monthly time frame in the present of the implementation of the best selected policy
- Determine and recommend alternative configurations and policies that could be applied to the real business

1.4 Methodology overview

To simulate a current system using ARENA software, test policies, and suggest production runtime in the case of increasing demand, the following steps were carried out:

- Collect data and develop the simulation model of the current state
- Verify and Validate the simulation model
- Calculate number of replicas using Sequencing Samplings method
- Analyze and test different policies
- Analyze production runtime after applied the best selected policy into the model

1.5 Scope

The study focuses only on the operations of outbound logistics for the quarry business with the goal to reduce both average flow time of trucks and loader's monthly traveling time and determine the best suitable policy. The simulation model is built upon the data collected on in the month of May and June 2018 and is used as the base model in the study. Policies are tested against the base model and only the best policy will be implemented in the production planning part in different cases of demand forecast. For the simplicity of the research, there are seven aggregate products and three types of customer that are subjected in this study.

1.6 Definition

The following definitions are used in this paper:

- **Outbound logistics**: logistics activities related to customers end in which includes all the activities from when an empty truck enters the system until a full truck leaves the system. The flow chart of outbound logistics can be seen in Figure 1.
- **Average flow time**: time a truck spent in the system; from the time a truck first enters the system at weigh station to the time the truck leaves the system after weight station. The average flow time is measured in minutes.
- **Work day**: a 9-hr operation in which there are six total work days per week.
- **Production hours**: The current average daily production hours of 5.5 hours (330 minutes). The current average daily production hours are considered a normal production hours during low season production. The low season of production hours resulted from a pause on production due to the uncertainty of the rain.
- **Trucks**: customers in the system. There are types of trucks: 6-wheeler (6T), 10-wheeler (10T), and double-axis-trailer truck (DT). This study uses truck and customer interchangeably.

- **Products**: final aggregate products that are ready to sell; currently there are seven types of products. Please note that products cannot be mixed, and this system assumes a full truck load when a truck is served.
- **Production rate**: rate of production of each product which is modeled in discrete manner in this study and that the breakdown of each product cannot be adjusted accordingly. The production rate used in this model is measured in ton/minute.
- **Loading time**: time the loader takes to fully load aggregate product on a truck and is measured in minute. Loading time differs based on type of trucks.
- **Weight carry**: the amount of weight a full truck can carry and is measured in ton. Weight carry differs based on type of trucks and type of products.
- **Traveling time (of loader)**: time loader takes to travel from one aggregate stockpile to another stockpile and is measured in second. It is to be noted that the traveling time excludes the loading time process.
- **Stockpile**: the end of conveyor line where aggregate products are located.

1.7 Assumptions and Limitations

- There are three types of truck subjected in this study: 6T, DT, and 10T receiving one of the seven aggregate products.
- Products received cannot be mixed and all customers want a full loading capacity.
- Trucks arrive based on hourly schedule, which differs throughout the day on a weekly pattern; each customer has a probability of choosing one out of seven aggregate products.
- The arrival schedule of truck customers assumes to be the same pattern regardless of the season.

- The production rate, although remains at constant rate throughout the production process, cannot be adjusted individually base on each product
- Current production run times (production hour) is 5.5 hour (330 min) per day which represents an average hours of production under a normal production run times for the period that data were collected
- The simulation model uses a monthly production time frame. Since the quarry operates 6 days a week, the run set up for the model is 24 days.
- Only one loader resource is subjected in this study.
- No transfer to stock process. This means that all inventory will eventually be built up at the bottom of each conveyor line.
- Although there is 9-hr operation a day, the system has to served all the incoming customers within the same day; this sometimes force the operation time to run further than 9 hours a day.
- Due date will not be considered in this study since all incoming customers has to be served within the same day.
- The simulation model is a terminating system with a specified amount of initial inventory and 24 days run-length.
- The study uses discrete tools to represent a material flow as big portions which is close to behavior of the continuous behavior of the actual quarry production.
- The study limits its focus only on improving policies on truck queueing and loader scheduling. There is one policy testing on truck queuing part (SPT), two policies testing on loader scheduling part (STT and MaxQ), and one last policy testing on both truck queueing and loader scheduling part (Combined).
- The study assumes five scenarios for the case of production planning. The five scenarios include 10%, 20%, 30%, 40%, and 50% increase in the number of incoming trucks (demand).

- Due to the time constraint and the availability of the data, the study uses the data collected between May – June 2018 as a base data when build the model. This implies that the nature of the model is close to the behavior of customer and production during the two months. In addition to this, the model does not take into the account of seasonal effect. This means that by using this model, it may not entirely represent high seasonal production during October – April nor entirely represent low seasonal production during July-September.
- The model does not take into the account of the buffer space of the physical area into the simulation model. This implies the model does not limit number of trucks that are waiting around the area.

Chapter 2: Literature review

2.1 Discrete simulation method (Arena)

The method of simulation provides a risk-free environment and saves money and time as compared to experimenting on a real asset; hence, many industries choose a simulation method in order to improve the current system. Arena is one of a well-known software that is widely selected to simulate a real-world problem into a simulation model to help test, analyze, and improve the system.

Arena is a discrete event simulation software based on SIMAN language that involves the use of flowchart and data modules. Flow chart modules define the processes to be simulated while data modules describe the characteristics of various process elements i.e. variables, resources, and queues. In the process of simulation, entities are created and as they move through the model, they are acted on by the module. Arena also contains function such input and output analyzer that fit the model and historical data to statistical distributions (Aytemiz 2004). In additional to this, ARENA can help analyze bottleneck for long duration process in order to reduce waiting time and reduce flow time (Eryilmax, Kusakci et al. 2012).

This research focuses on the topic of a new policy of truck queueing and loader scheduling. Since policy requires time to implement and training, they cannot be changed regularly. Hence the policy needs to be tested and analyzed using simulation model in order to reduce time and investment.

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2.2 The use of ARENA in mining industry

In mining industry, the use of simulation model has been widely used and Arena is selected as a tool to simulate a real problem. However, most study focuses on mining production planning and efficiency improvement of open-pit extraction logistics (inbound logistics) whereas this study focuses on the improvement of outbound logistics. Ataeepour and Baafi show that by using both built-in functions in Arena and layout of the mine system, Arena can help prove that dispatching policy is more productive than non-dispatching policy since it can minimize the queue time of trucks in open-pit area when waiting to be served by shovels (Ataeepour and Baafi 1999) . Kang et.al utilizes Transporter flowchart model in Arena to study productivity of truck movement transporting rock. Their study also simulates truck's speed reduction at the intersection as well as integrates a map representing the topography of the jobsite (Kang and Ahn 2006). Planning schedule, mining plan and forecasting production to reduce variance with the actual production can also be addressed using Arena simulation . In reality, although, a quarry production is close to continuous behavior, it can be model using discrete tools with a very precise presentation of the continuous behavior by modeling the material flow as big portions that are treated as discrete entities on the modeling code .

2.2.1 Truck-shovel operation

Truck and shovel operation is one of the examples showing how ARENA simulation can be used to model the operation. The truck and shovel operation focuses on how to improve the inbound raw crushed rock input (from open-pit extraction area) feeding into quarry machine. Ataeepour and Baafi used ARENA simulation model to study truck-shovel operation in both dispatching and non-dispatching model. The operation represented the process of five shovels loading rock into trucks. The study found that dispatching system was more productive than non-dispatching system since dispatching policy was based on minimizing the queue time of trucks when waiting to be served by shovels. If the utilization of trucks increased, the productive of the system improved. The study used both functions “expected delay time” and layout of the mine system (locations of objects and distances i.e. shovels, dumps, and routes) when simulating model in ARENA (Ataeepour and Baafi 1999).

Chaowasakoo et al also studied real time truck-dispatching decision using both discrete event simulation and GPS technology to help maximize the productivity while minimize the queueing time of trucks when waiting to be served by shovels. The study proposed three dispatching rules that were tested in the simulation model after a close examination on truck and shovel operation and collected enough historical information provided by GPS technology. The fundamental concept of their model was to developed truck allocation based on uncertain parameters. The parameters included (1) Hauling distance: depended on viability of trucks-shovels and dispatching orders; (2) Time of cyclic truck and shovel operation: depended on the hauling distance, speed of the truck, capacities of trucks and shovels, and the length of the queue; and (3) Loading time: depended on each type of truck since this is a heterogenous fleet (Chaowasakoo, Seppälä et al. 2017).

2.2.2 Transportation truck operation

Kang, Ahn and Nam studied the productivity of rock transportation trucks using ARENA. The study simulated a real situation of a new container terminal which was currently constructed; hence, the company wanted to excavate 23 million cubic meters of rocks from the 10 different locations on mountains within the next 30 months. The study utilized Transporter flowchart model in order to handle the trucks movement in the road and simulate the truck’s speed reduction at the intersection as well as integrated a map representing the topography of the jobsite with ARENA simulation model (Kang and Ahn 2006).

2.2.3 Production planning

Fioroni et al studied how simulation and optimization models could be used in mining planning. The objective of the study was to address short term schedule planning and monthly mining plan. The study also addressed the concern that when building a simulation model, it had to correctly represent the real system by capturing details level of “just enough” to reproduce the reality for the goals of the study. If the model was built with too detailed and complex, it would become slower and hard to understand (Fioroni, Bianchi et al. 2008). It could also lead to a reduction in the model reliability, as can be seen in Figure 2.

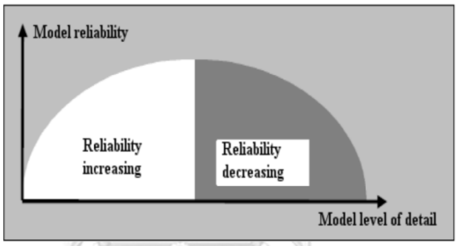

Figure 2: Reliability VS Level of detail

Another study done by Kaba, Temeng and Eshun also used ARENA with the objective of developing a stochastic model that was capable of forecasting production while reducing the variance of the actual production. ARENA was able to incorporate the variability input variables such as inclement weather and other unexpected production hitches. The study illustrated steps on how the model was built (Kaba, Temeng et al. 2016). Figure 3 to Figure 6 show example of ARENA models that were built and their steps can be summarized below:

- **Data collection:** loading time of trucks, hauling time of trucks, spotting and dumping time of trucks, trailing time of trucks, availability of shovels
- **Data analysis**: use Input analyzer of arena to determine type of distribution of cycle times of trucks

- **Model formulation:** model as a process where truck entities travelled from one station to another whereas stations includes dumps, loading faces, and parking areas. Modeling was done by organizing the modules into: trucks entity creating, shovel process, trucks movement, dumping process, and break time decisions.

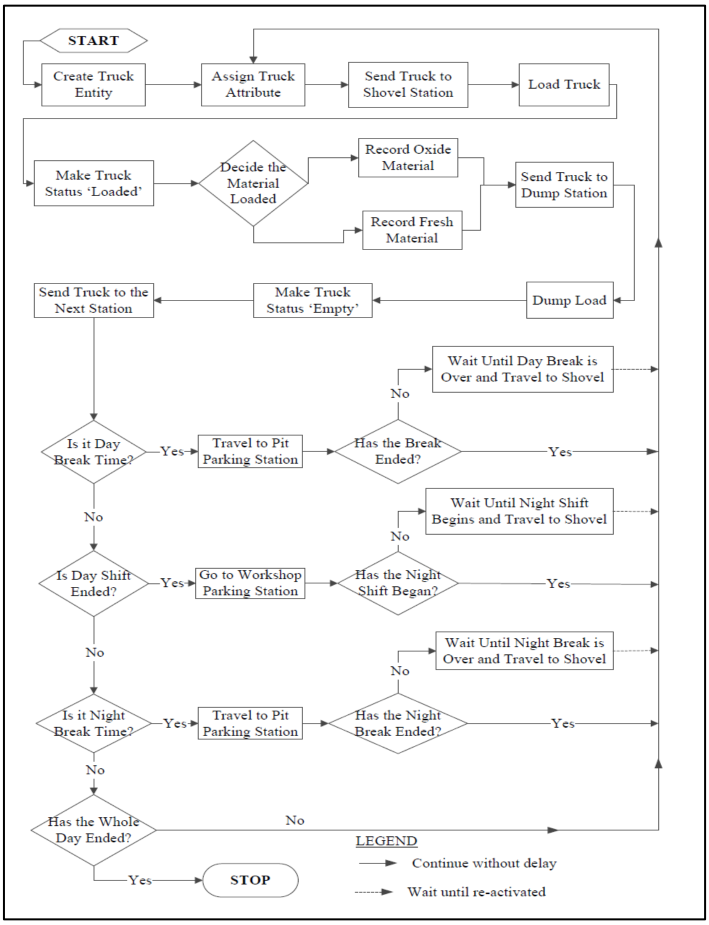

Figure 3: Example of conceptual model of shovel-truck system

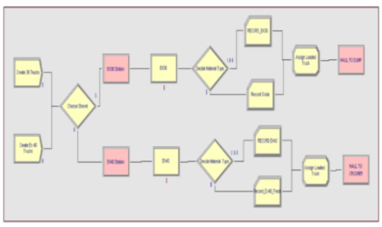

Figure 4: Example of trucks entities creation and shovel process

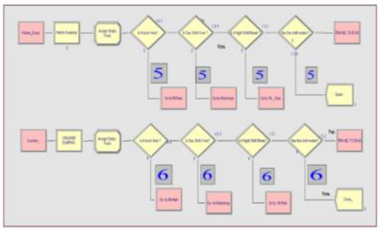

Figure 5: Example of dumping process and break time decisions

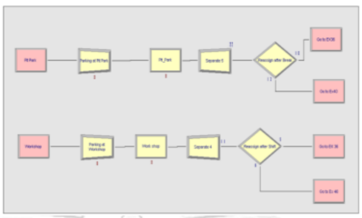

Figure 6: Example of break time modeling

2.2.4 Discrete modeling on continuous behavior of conveyor transport

When building a simulation model for mine production, it is essential to know whether the system is a discrete, continuous or a mixture of both. However, it is not always necessary to modeling the system the same as the real system is. Fioroni et al mentioned that "In some cases, the continuous behavior itself is not the most important thing to represent on the system, comparing with the complexity of the rules to use it" (Fioroni, Franzese et al. 2007). Their study presented a technique to model continuous behavior using just discrete modeling elements applying onto the conveyor ore transportation to a steel making plant. The paper proposed a way to model these systems with only discrete tools, but with a very precise presentation of the continuous behavior by modeling the material flow as big portions that were treated as discrete entities on the modeling code.

2.3 Number of replications

Number of replications is one of the key criteria that needs to be determined when running a simulation since it affects an estimation of the mean performance of some output from a simulation model. A study done by Hoad, Robinson and Davies summarized that there were four main methods on selecting the number of simulation replications (K., Robinson et al. 2010). The first is a rule-of-thumb method by Law and McComas. The idea was to make at least three to five independent runs for each alternative (Law 2002). The second is a simple graphical method by Robinson. The method suggested that when running a simulation model, it should be carried out in a series of replications and that a cumulative mean of a chosen output variable should be plotted against the number of replications. The idea was that where the cumulative mean line becomes 'flat' to the select number of replications, that point represent the number of replications (Robinson 1994). The third is confidence interval method by Law. The method allowed a user to specify the precision required for both confidence interval of the mean of the interested output variable as well as an acceptable significance level. The method suggested that replications are the run and that confidence intervals constructed around the sequential cumulative means until the desired precision in the output is achieved (Law 2007). The forth method described by Banks et al. is to predict the number of replications required from an initial set of replications. The method suggested to perform a few replications in order to generate an estimate of variance of the output data of interest. Then using the estimate of the variance and a required confidence interval half-width, the number of replications to achieve that half-width is calculated using a rearranged form of the standard confidence interval formula (Banks, Carson et al. 2005).

- By further developing a method to determine number of replications, Adewunmi and Byrne presented a method called Sequential Sampling (Adewunmi, Aickelin et al. 2008). This method helped with variance reduction and allowed the simulation to run until it reaches the specified confidence interval half-width before stops the run at "N" replication. By setting a large number of replications i.e. 1000, and making a choice regarding the target half-width and selecting the output performance measure of interest, the

Sequential Sampling “logic” helped check to see if the target half-width was achieved in each simulation run. Once it achieved the target, the model would stop running. Figure 7 represents the implementation of the Sequential Sampling method in Arena whereas the following summarizes the flow of activities of the Sequential Sampling logic:

- Entities are created and sent into a decide module,
- The decide module will check to see if the number of replications (NREP), is less than or equal to 2 (NREP is the number of initial simulation replications) and check that the target half width (ORUNHALF) has been achieved.
- If yes, the entity will be sent to the dispose module and the simulation will stop, otherwise it will keep replicating until the target half width has been achieved.

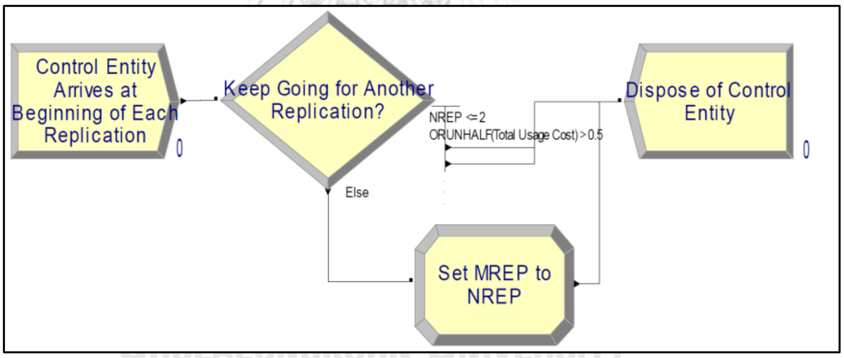

Figure 7: Modules for Sequential Sampling method in Arena to determine number of replications

2.4 Queuing and Scheduling Policy

2.4.1 Support logics and theories on queueing and scheduling

Queue begins when a queue of customers who need the service comes into a system. The queue process itself is a process starting from customer arrives into a service facility, waits in the queue line in order to be served, to customer finally leaves the facility after the completion of the service (Dehantoro, Sumiardi et al. 2016). Queuing theory is the study of queue or waiting lines. It includes but not limited to topic such as expected waiting time in the queue, average time in the system, expected queue length, and expected number of customers served at one time (Dharmawirya 2011). The queueing theory can be applied with statistical knowledge on flow time, in order to improve duration time (Wang, Ye et al. 2014).

Shortest Processing Time (SPT) is a well-known rule used in the field of job-shop scheduling and is known to be optimal if the objective is to minimize the average flowtime (Bobelin and He 2016). Hence, this paper proposes SPT policy to be tested in truck queueing issue in order to help reduce the average flow time a customer spent in the system. Chapter 4 will further illustrate the logic and method on how SPT policy is applied into the system.

Moreover, the paper also aims to minimize the time of loader transportation between different product stockpiles bases on the theory of Shortest Path Problem. Shortest Path Problem is a study of network flow in order to optimization the route and widely used in many transportation problems (Pallottino and Scutella 1998). The method relies on the logic of finding the shortest path or route from a starting point to a final destination (Magzhan and Jani 2013). By leveraging the idea of Shortest Path Problem into the current system of outbound logistics, a study proposes a policy called Shortest Traveling Time (STT). The STT policy is to be tested in loader scheduling issue in order to decrease loader’s total travel time.

In addition, the study also proposed Maximum Queueing Method (MaxQ) policy to be tested in loader scheduling issue. The maximum queueing method is based on the idea of identifying the bottleneck in a process and gives priority of work on that bottleneck area. A study done by Lawrence and Buss showed that the approach of identifying a bottleneck was that the entity with the longest queue length or waiting time was considered to be the bottleneck (Lawrence and Buss 1994). Chapter 5 will further illustrate the logic and method on how two testing policies, STT and MaxQ, are applied into the system addressing loader scheduling issue.

2.4.2 Examples of the use of queueing and scheduling technique

2.4.2.1 Queueing

The study done by Ahsan et al (2014) showed an example on how queueing technique can help improve the efficiency of the restaurant service. The study focused on the waiting time of customer in a restaurant that could lead to an opportunity lost due to a long wait on the line. The study showed that there were many factors that contribute to customers queueing time affecting the number of customer and overall efficiency including arrival time and service time. In the study, the average service time, average idle time, and average waiting time were measured. The increase number of servers was also tested in the study (Ahsan, Islam et al. 2014).

Dehantoro et al (2016) analyzed queuing system of vehicle service. The queue process began from customers arriving into the service facility, waiting in the queue to be served, until leaving the facility after the completion of the service. Arrival time, start time and finish time of the services were collected from four stations e.g. registration, servicing, final inspection, and billing service. Arena simulation was used to simulate simulation model and processing the data. The study found that lead time to service stall service contributed to 85% of the long lead time services vehicles and that the effectiveness of the best services was at stall service with utility services of 83.3% to the level of unemployed server 0.06%. The study also showed that the simulation model of the queueing could help manager making a better decision in order to balance the cost of the service (Dehantoro, Sumiardi et al. 2016).

2.4.2.2 Scheduling

A study done by Vernon and Richardson illustrated on how Arena can be used in truck maintenance operations that take place in the truck shop in mine production. Due to the fact that mining requires capital investment in equipment, a simulation model of mine site was built in order to improve by performance and provide insights into the truck shop operations. The objectives of this study were to build a working model of a truck shop operations and allow the model to be combined with a more advance mine model, evaluate resource allocation which affected on overall mine performance, evaluate the effect of varying queue priorities on overall mine performance, and provide a greater understanding of truck shop mechanisms. Queue priority was varied between ‘shovel first’ and ‘first in first out’ (FIFO) and scheduling was varied by the frequency of planned maintenance intervals. Each simulation ran for 100 replications for 100 days. The study found that an increase in truck leads to an increase in production and a decrease in availability. This could be explained by the fact that more truck yielded more dump loads resulted in an increase in production and that more trucks made the system to get congested and their downtime was lengthened as they waited in queues (decreased availability). The study also concluded that queueing priority given to shovels leads to greater mine performance than FIFO method (Vernon and Richardson 2010).

Another study done by Chang et al. focused on truck scheduling problem in the open-pit mine with different transport revenue. Truck was carried a full load of material such as ore, gangue, or other waste rocks. The electric shovel dumped the material to truck then returned back to shovel for the next round. The efficient truck scheduling not only could reduce the truck transportation cost but also increase the shovel utilization and the mine productivity. The study considered varied transportation revenue in different loading point as well as addressed the joint path planning and truck dispatching problem. The objective function was to maximize the total transport value. This problem was solved using the formulated mathematical models by CPLEX and the proposed heuristic approach. A heuristic solution approach with two improvement strategies was proposed to resolve the problem. The numerical experiments of proposed solution approach were effective and efficient (Chang, Ren et al. 2015).

2.5 The use of arena simulation in other industries

2.5.1 Sugar cane business

Aside from mining industry that use simulation to help with their inbound logistics improvement, sugar industry also uses modeling to help plan both their logistics and supply chain management. Iannoni and Morabito studied a simulation analysis in inbound feeding of sugar cane at the reception area process. The study wanted to analyze the performance of the reception area and investigated alternative policies for their operations. The goal was to have a continuous and uniform feeding of raw materials at the mill, maximized the unloading rate, and minimized the amount of raw material waiting in the unloading lines. The study tested three dispatching policies of reception area for the feeding sugar cane into the mill process, using discrete simulation analysis by building ARENA model. The dispatching instruction took into the account of queueing state of unloading lines, truck type, capacity of the mill, the state of intermediary storage, and product type (Iannoni and Morabito 2006). The simulation used two inputs (two different sugar cane), three dumping chutes (three mills), and four types of vehicles (four trucks).

Another study done by Gaucher, Le Gal and Soler emphasized the fact that a greater competitiveness in agribusiness can occur in the form of co-ordination between farmers and their clients to increase efficiency and profitability of the supply chain. Their study simulated based on two models: strategic and logistic model. Strategic model addressed mid-term strategic issues such as relocation of mills and investments in industrial to operations level such as planning of crushing season on weekly basis. Logistic model, on the other hand, addressed how sugar cane is conveyed from the fields to the mill on a daily basis. Their study showed that for logistics planning simulation need to be done in two models: (1) planning and operation of crushing part and (2) transportation and logistics part (Gaucher, Pierre-Yves et al. 2003).

2.5.2 Shoe manufacturing business

A study done by Eryilmax et al. used Arena simulation to help address the production policy in shoe manufacturing business over the combination of models which produced in daily working schedule. The production was a cellular production and with the production quantities and varieties, a production could be done in batches. The main characteristic of the shoe manufacturing was that the production was highly volatile and subjected to high variances depending on the model and rapidly changing trends of shoes fashion. The simulation model would provide a sensitivity analysis of the efficiency on the throughput rate and resource utilization. The study found that the bottleneck of the process was at the longest processing time. It also found that the variations of the shoes did not affect the flow time and cycle time, but affected the completion time of the process. The analysis of the queue helped address the waiting time and the number of waiting jobs, in which could be reduced by adding additional resources. In addition to this, the analysis of the resource utilizations was used to address the efficiency and productivity of the process (Eryilmax, Kusakci et al. 2012).

2.5.3 Packaging business

Aytemiz studied a simulation model of the packaging process of an automotive parts manufacturer in Connecticut with the use of Arena simulation model. Six experiments were conducted using the simulation to test the performance of the process. In addition to this the model was also conducted under as different simulation run. The study found that the current process flow showed that materials was over-utilized and under-utilized and that workload was not evenly distributed between the material handlers; hence, the modification of the process flow was necessary to balance the utilization of the material handlers. The study is a good example of how powerful simulation modeling is for analyzing the complicated systems and is very easy to perform what-if analysis in different scenarios on this system (Aytemiz 2004).

2.5.4 Textile business

On the other hand, Oliveira et al. presented simulation modeling of production scheduling problem in a textile company. The sequential processing included three operations of charging, weaving, and discharging. The study aimed to increase machine utilization due to short delivering deadlines, linear meter per hour of fabric, woven fabric per hour, man power utilization, and production time. This real problem could be modeled as a deterministic combinatorial optimization problem in variant of the multiple traveling salesman problems (mTSP) in which could be considered as a relaxation of the vehicle routing problem (VRP). The study ranked the interesting simulation software. The popularity ranking was choosing Arena Software to construct a model for real problem. Arena input analyzer functions were fitted to statistical distributions based on historical data and Arena professional included the functionality of OptQuest for optimizing systems. This research also tested the several factors of performance of four orders dispatching with four rules (Shortest Processing Time: SPT, Number of Bobbins: NOB, Earliest Due Date: EDD, Family Articles Processing: FAP). The result showed that FAP rule was the best option with machine utilization rate of 63%, in which is 16% better than the simulation model of the real production (Olivia et al., 2011).

2.5.5 Warehouse business

Warehouse is an important distribution center to receive and deliver for incoming and outgoing material. All the processes in warehouse are simultaneously loading and unloading systems. A study done by Liong and Loo used Arena simulation to simulate warehouse model. Real operation data was collected in a real time over a six days period during Monday to Saturday by interviewing the supervisor and workers. The study found that Tuesday had the longest waiting time and should be improved in order to achieve a certain satisfactory level for the waiting time. The study also explained that the higher number of replications run would lead to more precise models and that the tolerance of 10% was set for the validation. In addition to this, the study showed that field research enabled the researchers to understand the actual operations and to get the possible best design. Factors subjected in the study include an additional worker, service time, interarrival time of customer's trucks, replication period, and total number of trucks. The goal of the study was to find a strategy that could help optimize the residence time of customer's truck without affecting the other process. The study found that when other factors are relatively the same, the model overcame both overtime problem and reduces the waiting time for the customers by more than 65% (Liong and Loo 2009).

Chapter 3: Methodology

To simulate a current system using ARENA software, test policies, and suggest production runtime in the case of increase demand, the following steps were carried out: (1) Collect data and develop the simulation model of the current state, (2) Verify and Validate the simulation model, (3) Calculate number of replicas, (4) Analyze and test different policies to improve outbound logistics, and (5) Analyze production runtime after applied the best selected policy into the model.

3.1 Collect data and develop the simulation model of the current state

This study conducts a survey and collects data on the current state of the outbound system between the month of May-June 2018 for a total of seven weeks. At current state, there are seven aggregate products being served to three types of customers. Each product is assumed to be produced at a constant rate in unit of ton per minute. Loading time, moving time, weight-admin processing time, customer arrivals and departure times, and data regarding to customer's truck were collected.

Below show examples of the raw data that were collected during the period. In Table 2, starting time (time that trucks enter the system), ending time (time that truck leaves the system), duration (total time that truck spent in the system), type of truck, product, and weight of each customer truck were collected daily for a total of 42 days (7 weeks). Table 3 shows loading time data that were collected randomly for 50 samples by using both self-observation and stopwatch timing. In addition to the loading time data as appeared in Table 3, moving time to/from weigh station, weight-admin processing time were also collected randomly for 50 samples.

Table 2: Example of data collected on daily basis during the collecting period

Starting Time	Ending Time	Duration	Type of Truck	Product	Weight (ton)
7:3:48	7:13:11	0:09:23	6T	4	8500
7:4:13	7:13:36	0:09:23	10T	4	13650
7:5:48	8:14:34	1:08:46	10T	2	13400
7:6:24	8:3:48	0:57:24	10T	2	13700
7:18:45	8:10:52	0:52:07	6T	4	4630
7:21:4	9:1:37	1:40:33	DT	1	27610
7:23:3	9:33:47	2:10:44	DT	1	29710
7:24:56	9:8:59	1:44:03	DT	2	28740
7:26:15	9:29:12	2:02:57	6T	1	7110
7:26:57	9:18:10	1:51:13	10T	1	13590
7:30:19	8:9:1	0:38:42	6T	4	4240
7:32:9	8:36:19	1:04:10	6T	1	7670
7:33:44	8:31:46	0:58:02	6T	4	8000
7:34:22	8:59:29	1:25:07	DT	2	29430
7:55:20	9:7:7	1:11:47	DT	2	30960
7:59:7	8:57:19	0:58:12	DT	3	27430
8:0:54	9:15:21	1:14:27	6T	4	9840
8:6:45	9:16:45	1:10:00	6T	2	9040
8:7:46	8:53:2	0:45:16	6T	4	10010
8:9:40	8:37:42	0:28:02	DT	2	30340
8:10:21	8:43:9	0:32:48	6T	4	6660
8:15:32	9:10:40	0:55:08	DT	2	30720
8:21:36	9:27:21	1:05:45	6T	1	8370
8:22:6	9:13:38	0:51:32	6T	2	9550
8:30:35	8:56:0	0:25:25	DT	4	29500
8:40:27	9:21:16	0:40:49	DT	2	30450
8:41:32	9:14:32	0:33:00	6T	4	7980
8:42:2	9:36:36	0:54:34	6T	4	8580

Table 3: Example of raw data of loading time (min:second)

Loading Time (min:ss)		
6T	10T	DT
1:55	2:33	4:01
1:49	2:23	3:58
2:23	3:01	4:30
2:45	2:40	4:20
2:31	3:14	3:59
2:55	3:03	3:48
1:32	2:43	4:52
2:30	3:37	4:40
2:08	2:52	4:04
1:21	3:02	5:01
2:29	2:30	4:26
2:04	2:47	4:44
2:29	2:45	5:21

By using the flow chart of logistics outbound as illustrated in Figure 1, the current system can be simulated into a simulation model using ARENA software as appeared in Figure 8. There are four major sub-models that comprise the model of the current system: (1) *customer arrival sub-model*, (2) *production process sub-model*, (3) *weighing operations sub-model*, and (4) *loading operations sub-model*. In this study, when a new testing policy is implemented, there will be an adjustment or add-on modules in these four major sub-models.

Please noted that there are two other sub-models that also appears in Figure 8: *number of replica sub-model* and *exit sub-model*. The *number of replica sub-model* does not impact the flow of outbound logistics; thus, it will not be discussed under the major sub-model of the current system but will be later discussed separately under section 3.3 Calculate number of replica. The *Exit sub-model*, on the other hand, helps record additional information of the model and force each entity to leave the system; thus, the sub-model will not be further discussed.

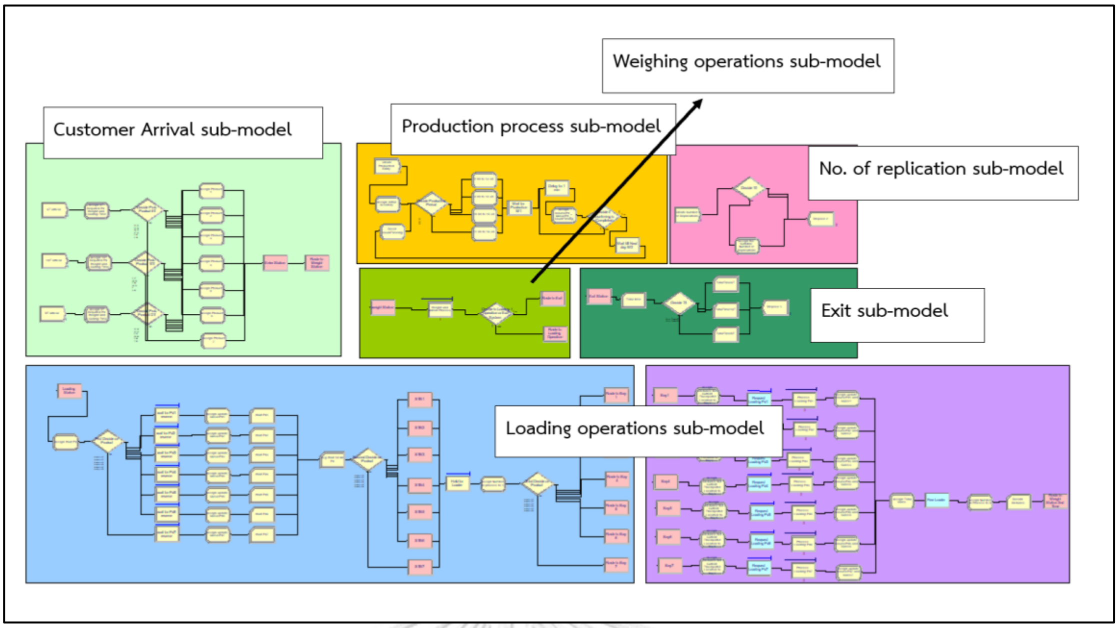

Figure 8: Simulation configuration (base model)

3.1.1 Customer arrival sub-model

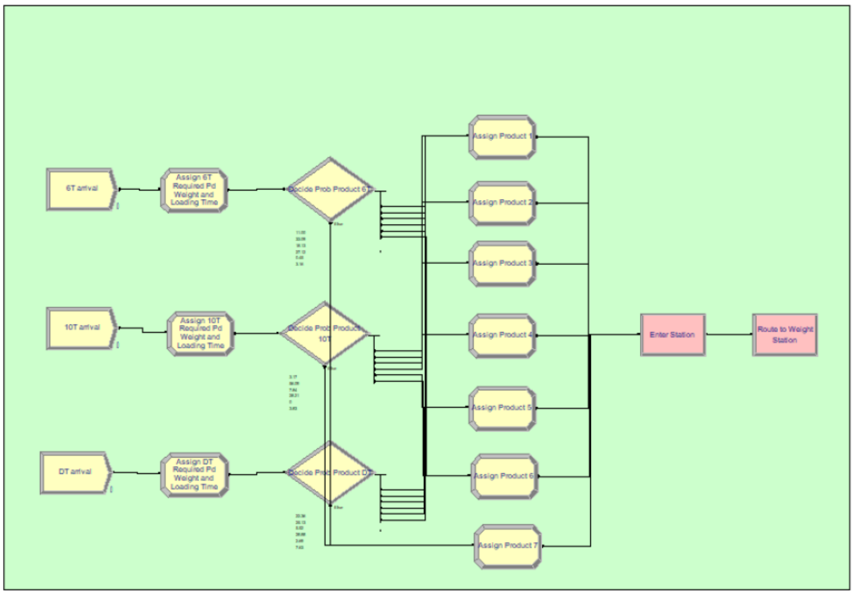

Figure 9: Simulation module for customer arrival sub-model

Figure 9 represents the flow of customer arrival into the system. Even though in the real situation all types of customer arrive all together throughout the day, in the simulation model each type of customers arrives base on its weekly arrival schedule.

In addition to this, since each truck knows beforehand what product it wants to purchase, the study applies the probability of the type of product purchase base on the type of each truck into the model.

Data on customer trucks arrival of all types of truck are collected together on a daily basis for seven weeks (42 days) before categorized based on the type of truck: 6T, 10T, and DT and the day of the week. For each type of truck's arrival schedule, the arrival rate has a pattern based on certain day of the week i.e. Monday pattern, Tuesday pattern, Wednesday pattern etc. with higher arrival rate in the morning and decreases down as day goes by. This means then when categorized the data base by day, there are seven Monday arrival patterns for 6T, seven Monday arrival patterns for 10T, and seven Monday arrival patterns for DT, and so on. Hence, the arrival rate was calculated by average the number of trucks arrival of each day depending on that type of truck. This results in the arrival rate of three types of customers 6T truck, 10T truck, DT truck, in six working days: Monday, Tuesday, Wednesday, Thursday, Friday, and Saturday, respectively, as appeared in Figure 10.

A one-hour time period is used to record how many customers, based on the type of customers in a certain working day, arrive in the system. The actual operating time operates for 9 hours a day, from 08:00 to 17:00 for six days a week. Figure 10 illustrates the arrival rate of each type of trucks following a pattern base on the day of the week whereas Table 4 shows an example of the arrival rate of each type of trucks on Monday. Please note that each bar in Figure 10 represents number of customers arrival in that hour period. For instance, the first two bars on the *Schedule 6T* (far left schedule in Figure 10) indicate that there are 11.0 customers arrive on Monday 8:00-9:00 time period and 9.3 customers arrive on Monday 9:00-10:00 time period.

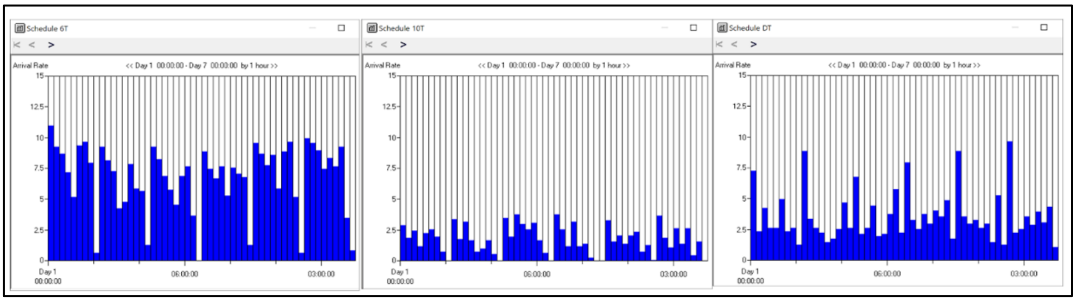

Figure 10: Arrival Schedule of 6T, 10T and DT Truck (from left to right)

Table 4: Example of the arrival rate (average number of incoming trucks) on Monday

Day	Period	Arrival Rate (number trucks in period)		
		6T	10T	DT
Monday	08:00-09:00	11	2.9	7.3
	09:00-10:00	9.3	1.9	2.4
	10:00-11:00	8.7	2.5	4.3
	11:00-12:00	7.2	1.2	2.7
	12:00-13:00	5.2	2.3	2.7
	13:00-14:00	9.4	2.6	5
	14:00-15:00	9.7	2	2.4
	15:00-16:00	8	0.8	2.7
	16:00-17:00	0.7	0	1.3

In addition to the arrival schedule that is needed to be identify in *customer arrival sub-model*, probability of choosing product base on the type of truck is also required. When a truck arrives in the system, it will be identified by the type of the truck and which product customer wants to buy. Each customer's truck can select only one type of product. The study also assumes that all type customers would buy a full load i.e. no customer can buy partial truck load. By using all the data from all trucks collected for seven weeks, the probability of choosing a product for each type of truck can be seen in Table 4. For instance, the probability of 6T truck customer choses product 1 is 11% whereas the probability of it choosing product 2 is 33.09%.

Table 5: Probability of choosing a product (percentage)

Product	Probability of choosing a product (percentage)		
	6T	10T	DT
1	11.00	3.17	22.36
2	33.09	56.09	25.13
3	18.13	7.84	5.52
4	27.12	28.21	28.88
5	0.45	0	2.69
6	3.16	3.83	7.63
7	7.05	0.86	7.79

3.1.2 Weighing operations sub-model

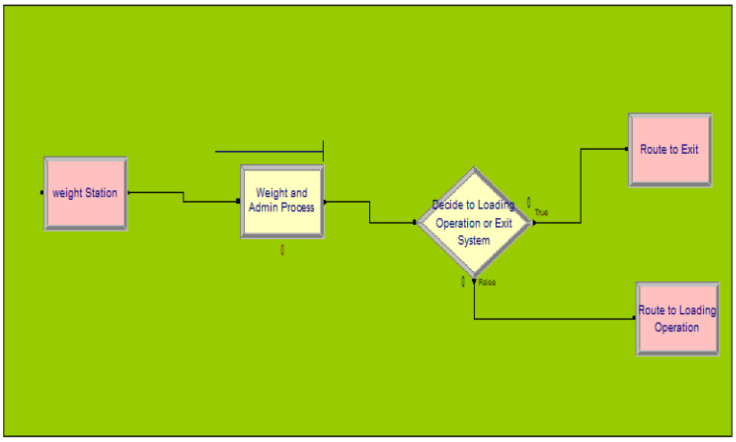

Figure 11: Simulation module for weigh operation sub-model

Once the truck entity leaves the *customer arrival sub-model* as appeared in Figure 9, it enters the *weigh operation sub-model* as appeared in Figure 11, which represents the operations of weighing and administration process. There are two times when a truck enters weight operation and contact the administration office. First is when it first arrives with an empty truck and later is when it is fully loaded and is about to leave the system. The time it takes to complete both weigh and administration process can be seen in Table 6, in which the distribution was calculated using Input Analyzer program (the example of how to use Input Analyzer program can be seen in Exhibit 1).

In addition to this, Table 6 also displays the time it takes for a truck to move from weigh station to loading area and the time the truck travels back from a loading area to the weigh station.

Table 6: Weight & admin processing time (sec) and moving to/from weight station `(min)

	Weigh & Admin Processing Time (sec)		Moving time to/from Weigh Station (min)	
	Distribution	P-value	Distribution	P-value
6T	UNIF(34.01,83.42)	0.345	UNIF(0.25,0.70)	0.534
10T	UNIF(34.01,83.42)	0.276	UNIF(1.70,2.50)	0.564
DT	UNIF(34.01,83.42)	0.234	UNIF(2.40,3)	0.454

3.1.3 Loading operations sub-model

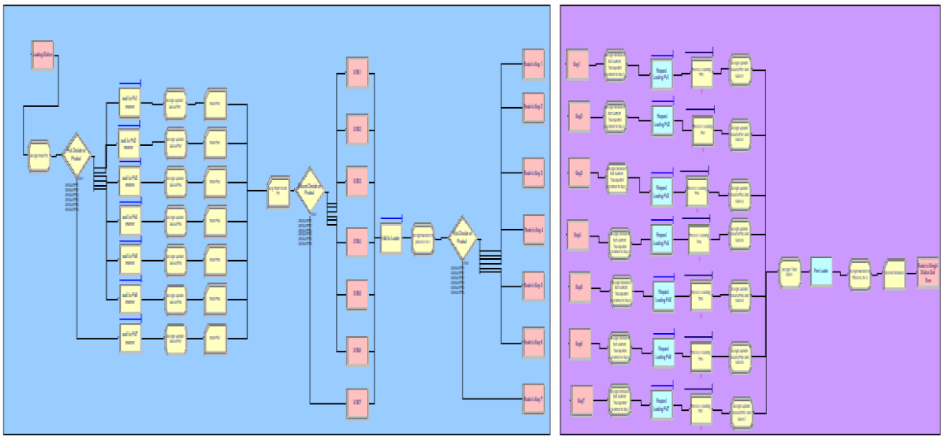

Figure 12: Simulation module for loading operation sub-model

Once the entity of truck leaves the *weigh operation sub-model* as appeared in Figure 11, it enters the *Loading operation sub-model* as appeared in Figure 12. It is to be noted that loading operation part is the most important sub-model part in this study since most of the testing policy will be applied and implemented into this part. The loading operation refers to when a loader fills up an aggregate for a full truck. The time it takes to fill can be seen in the Table 7, in which depends on the type of truck whereas the weight each truck can carried depends on the type of truck and type of product as can be seen in Table 8.

Table 7: Loading time (min)

	Loading time (min)	P-value
6T	1.23+WEIB(0.756,2.39)	0.310
10T	2+2*BETA(1.81,2.15)	0.246
DT	TRIA(3.52,4.19,5.88)	0.559

Table 8: Weight that each truck can carry (tons)

Product	Weight that each truck can carry (ton)					
	6T		10T		DT	
	Distribution	P-value	Distribution	P-value	Distribution	P-value
1	1+GAMM(0.59, 12.5)	0.345	11+20*BETA(0.37, 1.47)	0.234	8+WEIB(20.70, 7.17)	0.121
2	2+WEIB(6, 3.69)	0.456	NORM(14.10, 1.53)	0.143	10+ERLA(4.56, 4)	0.435
3	NORM(8.06, 2.10)	0.356	UNIF(11.06, 14.22)	0.532	5+26*BETA(1.21, 0.37)	0.325
4	WEIB(8.39, 4.64)	0.456	NORM(13.20, 1.67)	0.521	3+WEIB(26.60, 8.57)	0.345
5	TRIA(3.18, 6.09, 9)	0.422	0	0.121	WEIB(30.23,35.40)	0.456
6	3+LOGN(4.71, 2.60)	0.344	NORM(29.4, 2.86)	0.435	8+WEIB(21.60, 12.80)	0.356
7	3+LOGN(10.4, 13.70)	0.235	NORM(29.4, 2.86)	0.325	NORM(30.40, 2.86)	0.532

There are two queues that happen in process: in blue area and purple area, as appear in Figure 12. First is production reserve queue (blue area) which resulted from not having enough product in stockpile. This means that the system will hold trucks in the blue area until there is enough product to be served. Once the system releases the truck, the truck will line up in each product's queue in the purple area base on FIFO on each line. The second queue in purple area is called loader queue which resulted from trucks who wait for loader to run back and serve them. In the current base model, FIFO queue is used when loader calls for a customer truck to be served. In addition to this, the study also considers a traveling time the loader travels from one stockpile to another stockpile. Traveling time between each stockpile or product position (in second) can be seen in Table 9. Please noted that the first queue in the blue area will be addressed under truck queueing policy whereas the second queue in the purple area will be addressed under loader scheduling policy.

Table 9: Traveling time-distance (sec) between product stockpiles

seconds		Product Position						
		1	2	3	4	5	6	7
Product Position	1	0	19	32	39	45	47	50
	2	19	0	12	19	26	27	30
	3	32	12	0	7	13	15	18
	4	39	19	7	0	6	8	11
	5	45	26	13	6	0	2	4
	6	47	27	15	8	2	0	3
	7	50	30	18	11	4	3	0

Once a truck customer has received products at the end of the loading process, it will travel back to *weight operation sub-model* to do a second weighing before leaving the system via *exit sub-model.*

3.1.4 Production process sub-model

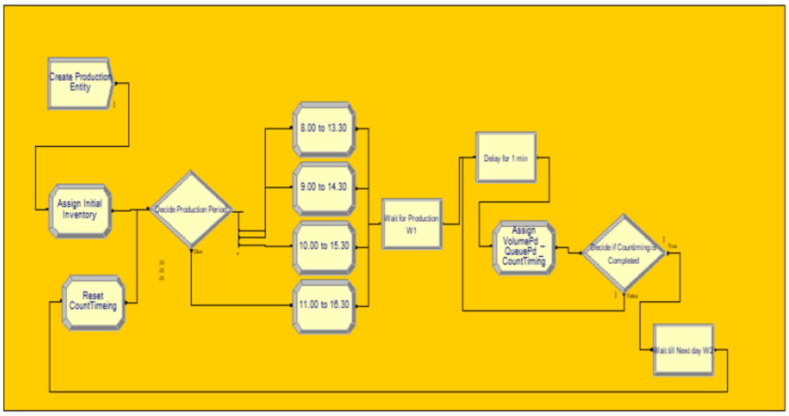

Figure 13: Simulation module for production process sub-model

Although *production process sub-model* does not directly connect to the flow of trucks entity as previously discussed in the previous three sub-models (*customer arrival sub-model, weighing sub-model, and loading sub-model*), the *production* *process sub-model* still greatly impacts the flow of the logistics since it affects the wait time for each product when there is insufficient product in the system. Figure 13 illustrates the sub-model of production process. Although the system operates under a normal operating time of 9 hours, the current production line only runs on average of 5.5 hours per day. This is considered a normal operation during low season production since there are always a pause on production due to an uncertainty of rain. In order for a simulation model to capture to a closer state of the current production line, the study assumes four production patterns with equal probability in the current simulation model, as can be seen in Figure 13. The patterns are the following: (1) 8:00-13:30, (2) 9:00-14:30, (3) 10:00-15:30 and (4) 11:00-16:30 and each pattern is assumed with a 0.25 probability of occurring. In addition to this, the production rate (ton/min) for each product is also built into the module.

Production rate determines the amount of production in tons of each product that is produced in a minute. Since the actual production run time and amount of production of each product varies on a day, the production rate in this study represents an average production rate during the collecting period with the unit of ton/min. Although in reality, a quarry production is close to continuous behavior, the study uses discrete tools to represent a material flow as big portions which is close to behavior of the continuous behavior. The production rate of each product can be seen in Table 10. For instance, the production rate of product 2 is at 2.5 ton/min, etc.

Table 10: Production rate (ton/min)

Product	Production Rate (ton/min)
1	0.71
2	2.5
3	0.64
4	1.27
5	0.13
6	0.51
7	0.64

3.1.5 Results of the base model

The study found that with the current base model, the average flow time a truck spent in the system is 39.22 minutes whereas the monthly traveling time of loader is 41889.36 seconds. It can also be seen that the average wait time for products in the current system is 20.97 minutes. Table 11 summarizes Arena result of the base model. It is to be noted that the current base model uses 101 replications to achieve the result represented in Table 11. The calculation of number of replicas will later be discussed in Section 3.3

Table 11: Average flow time, monthly traveling time and average wait time for products for Base model

Policy	Avg Flow Time of Truck (min)		Monthly Traveling Time of Loader (sec)		Avg Wait time for Products (min)	
	Average	Half Width	Average	Half Width	Average	Half Width
Base Case	39.22	5.58	41889.36	205.31	20.97	5.58

3.2 Verify and validate the simulation model

3.2.1 Verify the simulation model

For a simplicity of verification purpose, the model is run under simpler characteristics. This means that the run setup for the verification will be set as the following:

- Replication length = 6 days (1 week)
- Number of replications = 1 rep
- Initial volume of product (i) = 0
- Daily production time = 5.5 hr (330 min)
- Daily operating hours = 9 hr (540 min)
- Production rate for a product (i) = 1 ton/min

(Thus, for 7 products, total production rate = 7 tons/min)

- 6T truck carries = 1 ton
- 10T truck carries = 2 tons
- DT truck carries = 3 tons
- Truck only requires Product 1
- Incoming number of trucks number are preset at 100 trucks for 6T truck, 200 trucks for 10T truck and 300 trucks for DT truck

Hence, the study is able to verify the following four criteria include (1) production amount, (2) selling amount, (3) remaining amount of products, (4) production graph of each scenario, which can be discussed below:

3.2.1.1 Production amount verification

The weekly production runs for 6 days x 5.5 hr/day x 60 min/hr x 1 ton of product (i) /min x 7 products. Therefore, the production per week = 6 x 5.5 x 60 x 1 x 7 = 13860 tons which equals to *Total Productions* output result from Arena in Figure 14.

Output	Value
Remaining Vol 1	580.00
Remaining Vol 2	1980.00
Remaining Vol 3	1980.00
Remaining Vol 4	1980.00
Remaining Vol 5	1980.00
Remaining Vol 6	1980.00
Remaining Vol 7	1980.00
S1	1400.00
S2	0.00
S3	0.00
S4	0.00
S5	0.00
S6	0.00
S7	0.00
Total 10T out	200.00
Total 6T out	100.00
Total all T out	600.00
Total DT out	300.00
Total Productions	13860.00
Total Remaining Volume	12460.00
Total Sale	1400.00

Figure 14: Arena output result for verification purpose

3.2.1.2 Selling amount verification

The total selling amount can be calculated using the formula = Sum of (trucks(i) x weight(i)). From Figure 14, it can be seen that the total number of trucks in a week for 6T, 10T and DT (*Total 6T out, Total 10T out, Total DT out* output*)* are 100, 200, and 300 trucks, respectively. Please note that for the simplicity of verification purpose, the assumptions are made that 6T truck requires 1 tons of product 1T, 10T truck requires 2 tons of product, and DT truck requires 3 tons of product. By using the total selling amount formula, it can be seen that the weekly total selling amount = (100×1) + (200×2) + (300×3) = 1400 tons which equals to *Total Sale* output result from Arena in Figure 14.

In addition to this, since the assumption for verification part assumes that there is only a demand for Product 1. Hence, when using Arena output result from Figure 14, it can also be seen that Total Sale = Total Sale of Product 1 (*S1* output) = Total Production of Product 1 (*Total Productions* output */ 7*) – Remaining of Product 1 (*Remaining Vol 1* output) = 13860/7 – 580 = 1980 – 580 = 1400 tons.

3.2.1.3 Remaining amount of products verification

The remaining amount of products can be calculated using the formula = Total production - Total selling = Sum of (Remaining amount of product (i)). By using information from Arena output result from Figure 14, the first half of the equation becomes:

Total remaining (Total Remaining Volume output) =

Total Production (Total Productions output) - Total Sale (Total Sale output)

12460 = 13860 – 1400,

whereas the latter half of the equation becomes

Total remaining (Total Remaining Volume output) =

Remaining Vol 1 + Remaining Vol 2+ …+ Remaining Vol 7 output

12460 = 580+1980+1980+1980+1980+1980+1980

3.2.1.4 Production graph of each scenario verification

To capture the closer state of the current production line with average daily production hours of 5.5 hours, the *production sub-model* is built using four production patterns in order to capture the uncertainties and the randomness of the production hours that is caused from the seasonal effect such as rain. The four patterns are the following: (1) 8:00-13:30, (2) 9:00-14:30, (3) 10:00-15:30 and (4) 11:00-16:30, and each pattern is assumed with a 0.25 probability of occurring. In order to verify each production pattern, that selected production pattern will be assumed a probability of occurring of 1.0 while the other three patterns will be assumed a probability of occurring of 0. Figure 15 to Figure 18 show a production graph of each scenario.

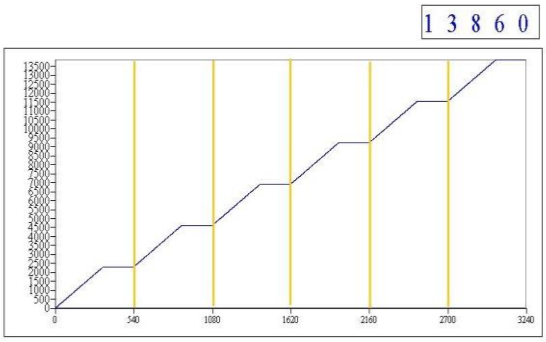

Figure 15: Production Time 8:00-13:30 (production time vs tons produced)

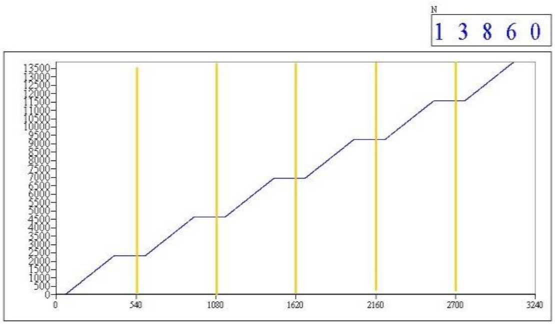

Figure 16: Production Time 9:00-14:30 (production time vs tons produced)

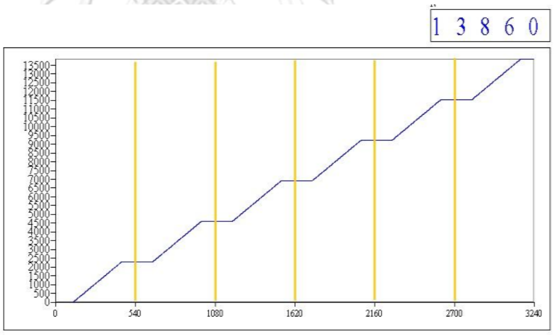

Figure 17: Production Time 10:00-15:30 (production time vs tons produced)

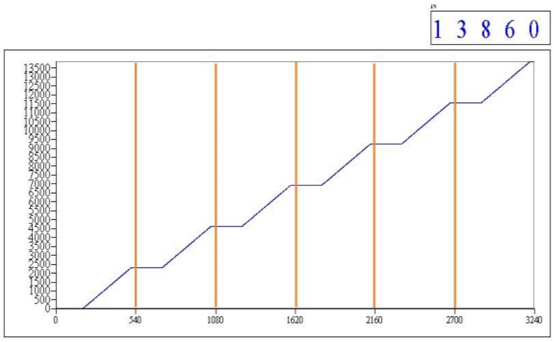

Figure 18: Production Time 11:00-16:30 (production time vs tons produced)

To further explain each production pattern, Figure 15 is selected as the example. The probability of occurring of 1.0, in the case of Figure 15, means that with this production pattern, the quarry will only operate its production line only between 8:00-13:30 (5.5 hours). In the figure, it is to be noted that x-axis represents the amount of production run time (in minutes) whereas y-axis represents the amount of products produced (tons). In addition to this, the six divisions by the yellow vertical line represents six work days in a week, in which one work day is with operating hours of 9 hours (540 minutes). Each slope represents a production run time of 5.5 hours (330 minutes) in that particular day, whereas the flat line represents the none-production hours of 3.5 hours (210 minutes). The top right corner of Figure 15 also shows that the total amount of weekly production is 13,860 tons.

3.2.2 Validate the simulation model

Since the study is interested in a particular time period and because productions always exceed demands, the system never reach a steady state. Figure 19 also shows the historical data of total monthly production versus monthly sales in each month between 2014 - 2018 that the supply always exceeds the demand. Therefore, the system is a terminating system and that there is no warm up period. This means that when running the simulation model, both initial states i.e. initial volume of each product and run length are specified. Table 12 shows the initial amount of each product that is set before the simulation run whereas Figure 20 shows that the run length (replication length) is set at 24 days and with 9 hours per day. Please note that 24 days represent a monthly production time frame under the study's assumption in which there is 6 working days a week.

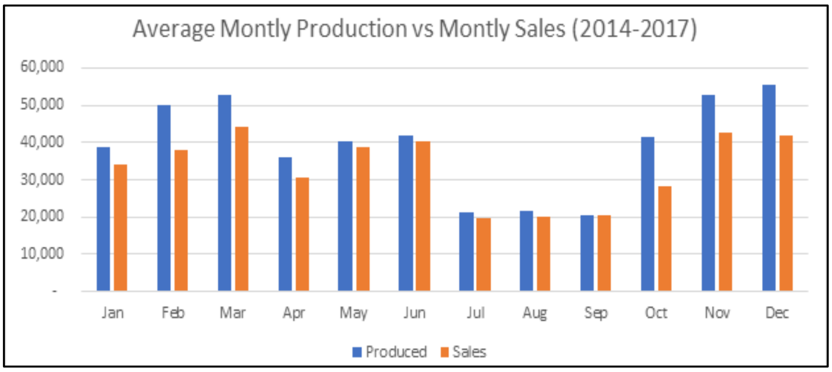

Figure 19: Average monthly production (tons) vs monthly sales (2014 - 2017)

Table 12: Amount of initial volume of each product before the simulation run

Product	Initial Volume (tons)
1	882
1	882
2	350
3	493
4	689
5	130
6	512
7	965

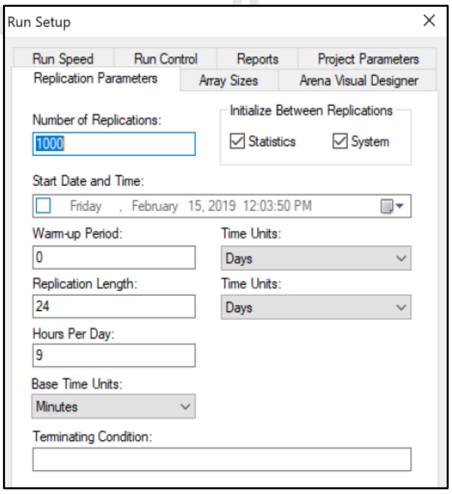

Figure 20: Arena's run set up

Although the model run set up was set to be 24-days run length (4 weeks = 24 days), a weekly basis is used when validate, compare and check the model. This indicates that the numbers for mean (*Mean*) and halfwidth (*HW*) of 24-days run length resulted from ARENA are to be calculated into a new mean (*Mean'*) and new standard deviation (*S'*) of a weekly basis before compared to a real collected data using the following equations. Please note that although initial number of replications was set at 1000, the simulation comes to an end at N = 101 replications. Hence, N = 101 replications will be used in the converting equations. The following converting three equations are used:

$$S = N \times \frac{HW}{Z_{\frac{\alpha}{2}}} \qquad (1)$$

$$Mean' = \frac{Mean}{4} \qquad (2)$$

$$S' = \frac{S}{4} \qquad (3)$$

where α = 0.05, N = number of replications,

Mean' and S': mean and standard deviation of 6 days run length,

Mean and S: mean and standard deviation of 24 days run length

Once a new mean (*Mean'*) and new standard deviation (*S'*) of a weekly basis are calculated, the study uses two-sample t-test with a significant level of 0.05 to validate the model against a real data. The hypothesis of testing, which appears in equation below, is to see whether the two data sets is significantly different or not. In this study, p-value more than 0.05 indicates the "fail to reject H_0" which means that there it is not significantly different between the two data sets.

H_0: u1- u2 $=$ 0, Accept H_0 if and only if p value $\geq$ 0.05 (4)

H_1: u1 -u2 $\neq$ 0

Using the following parameters: number of each type of trucks out in each week, total time spent for each type of truck, and amount sold in each week of each product, the study proves that all the selected parameter passes the statistical test since the p-value is greater than 0.05 for all parameters. Therefore, it can be concluded that with 95% confidence there is no significant difference occurred between the model and the real data sampling. By using Minitab software, the two sample T-Test can be statistically tested. Figure 21 shows example on how the output result from Minitab software look like. From the figure, the p-value of number of 6T truck is 0.486 which is greater than 0.05. This indicates that the result passes the statistical test and there is no significant difference between the model and the real data sampling for number of 6T truck. Table 12, Table 13, and Table 14 summarize p-value for the selected parameter. For further two-sample t-test details of other parameters, please refer to Exhibit 2.

Two-Sample T-Test and CI

```
Sample    N   Mean  StDev  SE Mean
1         7  344.9   73.8       28
2       101  365.6   10.2      1.0


Difference = mu (1) - mu (2)
Estimate for difference:  -20.7
95% CI for difference:  (-89.0, 47.6)
T-Test of difference = 0 (vs not =): T-Value = -0.74  P-Value = 0.486  DF = 6
```

Figure 21: Two-sample T-Test of Number of 6T trucks

Table 13: Parameters used for Validation: Number of trucks (1 week)

Number of trucks (1 week)				
Truck	Source	Average	Standard deviation	P-value
6T	Real	344.9	73.8	0.486
	Model	365.6	10.2	
10T	Real	81.3	26.0	0.164
	Model	96.9	5.1	
DT	Real	192.1	18.8	0.998
	Model	192.2	6.5	

Table 14: Parameters used for validation: Total time spent for each truck

Total time spent for each truck (min)				
Truck	Source	Average	Standard deviation	P-value
6T	Real	30.3	24.0	0.073
	Model	35.4	27.2	
10T	Real	35.7	34.8	0.631
	Model	37.3	25.7	
DT	Real	45.0	39.2	0.533
	Model	47.4	33.8	

Table 15: Parameters used for validation: Amount sold in each week for each product

Amount sold in each week of each product (tons)				
Product	**Source**	**Average**	**Standard deviation**	**P-value**
1	Real	1533.3	699.7	0.954
	Model	1549.1	69.4	
2	Real	2862.9	504.6	0.391
	Model	3039.8	124.5	
3	Real	811.7	278.5	0.467
	Model	893.5	57.2	
4	Real	2700.5	1023.8	0.901
	Model	2650.5	53.8	
5	Real	182.8	209.3	0.853
	Model	167.5	34.0	
6	Real	588.3	314.9	0.744
	Model	629.1	63.3	
7	Real	495.5	480.9	0.114
	Model	832.2	81.1	

3.3 Calculate number of replicas using Sequential Sampling methods

In this study, the calculation of number of replicas is a built-in module that is already included in the simulation model as can be seen in the top right of the simulation configuration in Figure 8, called *number of replica sub-model*. The study uses Sequential Sampling method to attain a desired 95% confidence interval of chosen parameters as a calculation base for number of replicas. Total time of 6T, 10T, DT, and overall total time are selected as the output performance measure of interest and that a pre-set big number of replicas is 1000. By doing so, it can help the model with variance reduction and allows the simulation to run until it reaches the specified confidence interval halfwidth before stops the run at “N” replication.

The submodel function ORUNHALF (OutputID) is used to returns the value of the half-width of the 95% confidence interval around the mean for a particular output statistic across all replications run so far. It considers only the final values of the completed replications. Since the study choses Total time of 6T, 10T, DT, and overall total time to be the output performances, the ORUNHALF function for the Sequential Sampling terminating models is written as the following:

```
ORUNHALF (Total time)         > 0.5   &&
ORUNHALF (TotalTime6T)        > 0.5   &&
ORUNHALF (TotalTime10T)       > 0.5   &&
ORUNHALF (TotalTimeDT)        > 0.5
```

The study found that at N = 101 replications, the model attains a desired 95% confidence interval half-width of the mentioned output parameters.

3.4 Analyze and test different policies

There are two main parts that a testing policy could be implemented into. First is the truck queueing part and second is loader scheduling part. In this study, four policies are implemented into the model. The first one (SPT) focuses on improving truck queueing part; the next two (STT and MaxQ) focus on improving loader scheduling part; and the last one (Combined) focuses on improving both truck queueing and loader scheduling part.

The following contains logic that is used to build each testing policy:

3.4.1 Truck Queuing policy: Shortest Processing Time (of customer) policy (SPT policy)

This policy gives priority to truck with lower processing time. Since the average processing time for 6T, 10T and DT is 2:04 min, 2:54 min and 4:41 min, respectively, the priority for 6T, 10T, DT is in descending order. This implies that when all the trucks waiting in queue, truck with higher priority (6T) will pass truck with lower priority (10T and DT, respectively). For the SPT policy to work, the priority attribute is created in addition to the base model. Please note that this policy does not affect loader scheduling; hence, loading still serves trucks based on FIFO.

In order to implement the policy into the current simulation model, it requires an adjustment of the *customer arrival sub-model* and *loading operations sub-model*. Figure 22 and Figure 23 show what the *customer arrival sub-model* and *loading operations sub-model* would look like when SPT policy is implemented into the simulation model. Although a part of the model may look the same as those of the current base model, the orange color appears in the figure indicates that the module detail is different. More details on SPT policy including its result will be further discussed in Chapter 4.

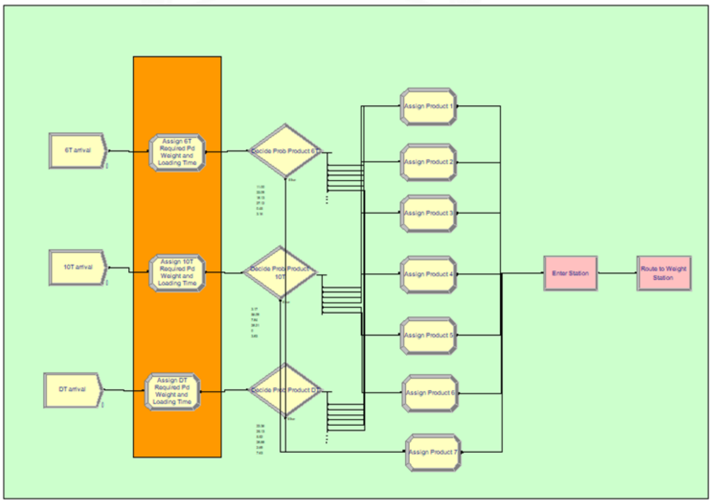

Figure 22: SPT's customer arrival module

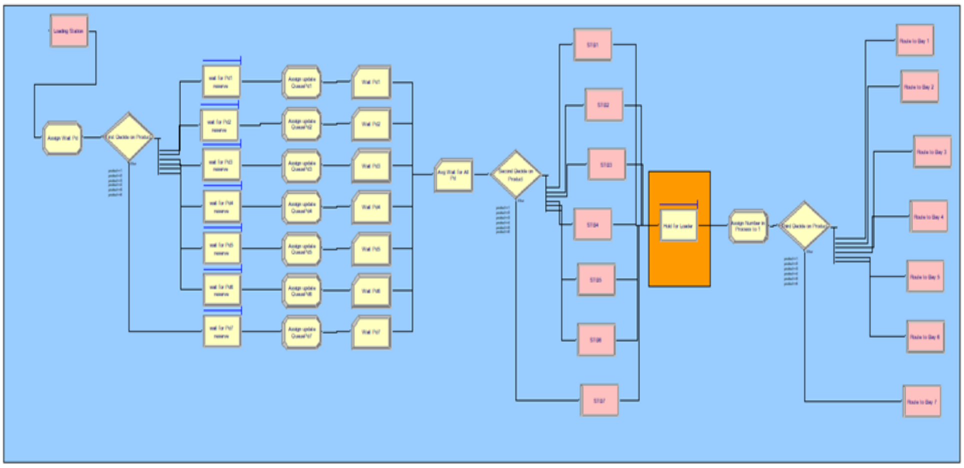

Figure 23: SPT's loading operation module

3.4.2 Loader Scheduling policy: Shortest Traveling Time (of loader) policy (STT policy)

This policy applies the idea of shortest traveling time of loader. Since there is only one loader serving in the system choosing among seven products, STT policy will ask the loader to move to the product stockpile which locates next (closest) to the current one. In this policy, it is also assumed that the loader cannot return to the previous stockpile that it had served before the current stockpile. This can be concluded that the pattern that loader will move will be 1,2,3,4,5,6,7 then 7,6,5,4,3,2,1. In addition to this, since the goal is to minimize loader traveling time, a batch of "n" trucks is allowed. This means that if there happens to have multiple trucks who request the same product as to where loader is currently serving, loader will also serve those few more trucks depending on a designated batch size before moving to the next stockpile. Please note that while batching trucks of the same product could help enhance loader scheduling policy since it would reduce traveling distance of loader, it is not necessary means that the higher batch would result in a better process performance.

In order to implement the policy into the current simulation model, it requires an adjustment of the *loading operations sub-model*. Figure 24 and Figure 25 show what the *loading operations sub-model* would look like when STT policy is implemented into the simulation model. Although part of the model may look the same as those of the current base model, the orange color appears in the figure indicates that the module detail is different. More details on STT policy including its result will be further discussed in Chapter 5.

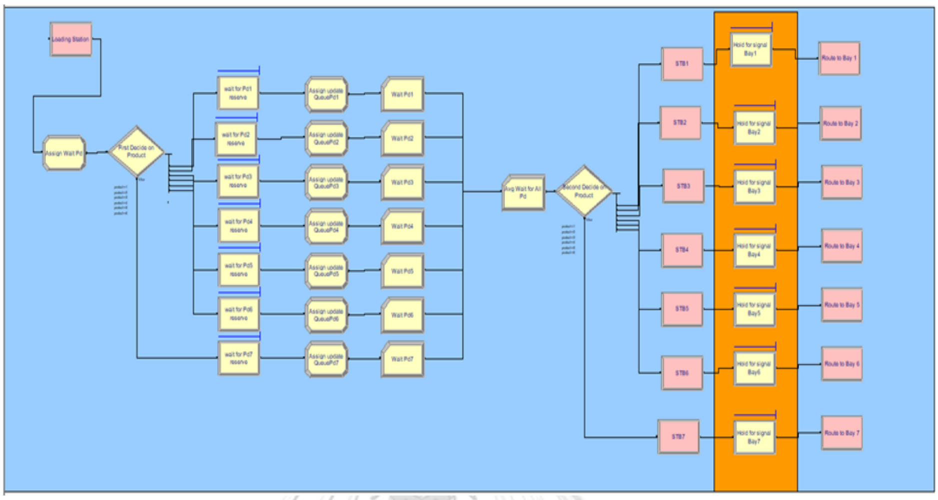

Figure 24: STT's loading Operation module

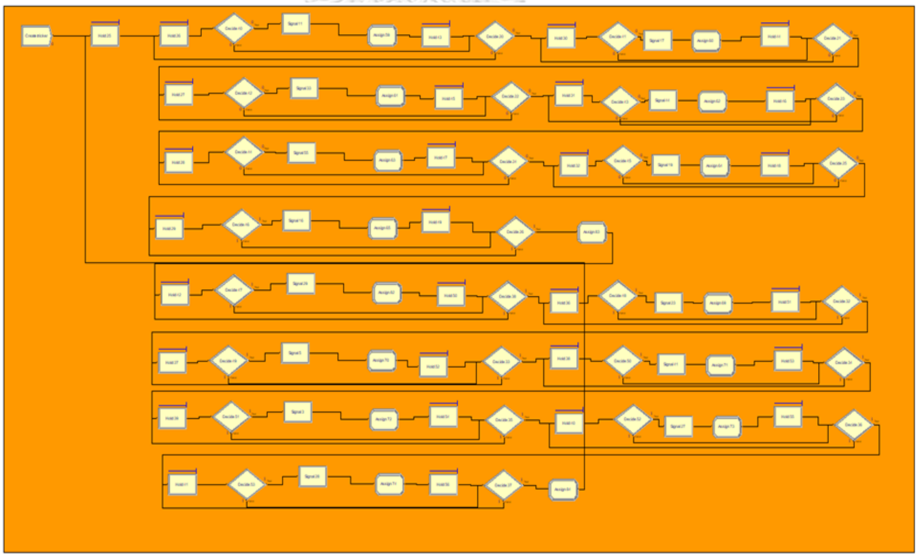

Figure 25: STT's loading Operation module part 2

3.4.3 Loader Scheduling policy: Maximum Number in Queue policy (MaxQ policy)

This policy utilizes the idea of identifying the bottleneck in a process and gives priority of work on that bottleneck area first. The physical area constraint of the quarry limits the number of trucks that could be in the system at the same time. This implies that the longer queue length in a particular product line results in the bottleneck of the system since it creates traffic and takes a lot of space. In MaxQ policy, loader will first serve the longest queue length of a product. To simply put, the system will analyze which product line has the longest queue at a current time and gives signal to loader to work on that product line. In addition to this, a batch of “n” truck is also be applied if within the current serving product line has multiple trucks waiting at the point in time. Once loader finishes serving a truck and checking if there is a need for batch serving, the system will re-evaluate the next longest product line.

In order to implement the policy into the current simulation model, it requires an adjustment of the *loading operations sub-model*. Figure 26 and Figure 27 show what the *loading operations sub-model* would look like when MaxQ Policy is implemented into the simulation model. Although part of the model may look the same as those of the current base model, the orange color appears in the figure indicates that the module detail is different. More details on MaxQ Policy including its result will be further discussed in Chapter 5.

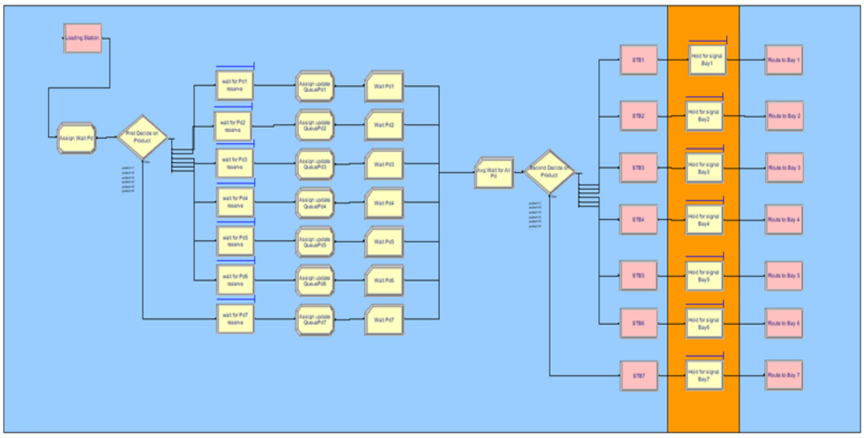

Figure 26: MaxQ’s loading Operation module part 1

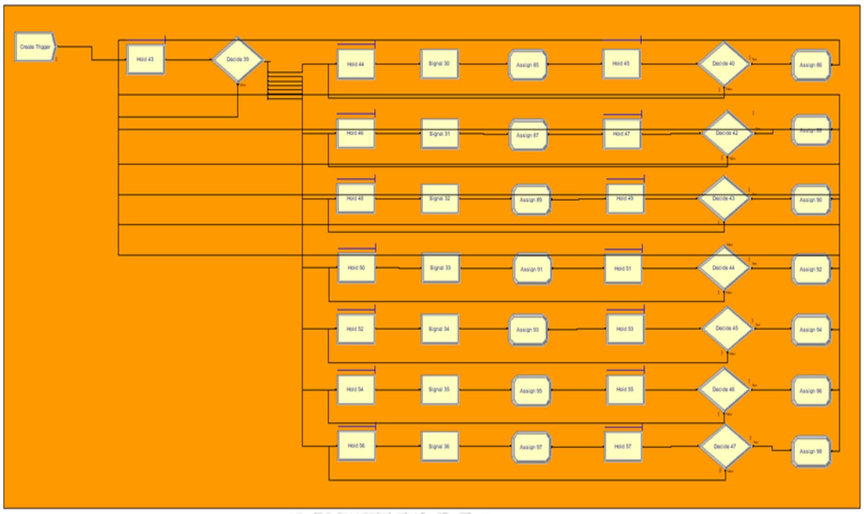

Figure 27: MaxQ's loading Operation module part 2

3.4.4 Combined Policy (SPT policy & STT policy)

The combined policy help improving both truck queueing and loader scheduling part. This policy selected the best policy from truck queueing policy, which is SPT, and loader scheduling policy, which is STT, and combined them together. More details on Combined Policy including its result will be further discussed in the next chapter.

3.5 Analyze production runtime after applied the best selected policy into the current model

After the best policy has been determined, the study further addresses the issue of production adjustment of the system in the case of increasing trend in demand with the implementation of the policy. The forecast of future demand is broken down into five different scenarios of the increasing number of incoming trucks by 10%, 20%, 30%, 40%, and 50%. The study uses Process Analyzer Software to help calculate and analyze the appropriate production run time in each scenario.

Figure 28 illustrates the example of the result from Process Analyzer for the case of 10% demand increasing case. Two factors under Controls: *Working* (Daily average production time) and *WaitforFree* (Non-production time) act as an input control for each case, whereas two factors under Response: *Total sales* (Monthly total sales) and *Total time* (Total time spent) represent result from the input combination. Please note that the study assumes that there is 540 minutes or 9 hours working hours per day. Row 6 from Figure 28 indicates that with the daily average production time of 410 min and non-production time of 130 min, the scenario setting yields the monthly total sales 43419 tons and the average time a truck spent in the system of 14.92 minutes. More details on Production planning for a future change in demand will be further discussed in the section 4.3.

	Scenario Properties				Controls		Responses	
	S	Name	Program File	Reps	Working	WaitforFree	Total sales	Total time
1		Scenario 12	24 : Rule4Ne	101	330.0000	210.0000	41690.282	113.285
2		Scenario 13	24 : Rule4Ne	101	350.0000	190.0000	42566.195	58.251
3		Scenario 14	24 : Rule4Ne	101	370.0000	170.0000	43138.713	25.117
4		Scenario 15	24 : Rule4Ne	101	390.0000	150.0000	43372.617	16.758
5		Scenario 16	24 : Rule4Ne	101	410.0000	130.0000	43411.760	15.126
6		Scenario 17	24 : Rule4Ne	101	430.0000	110.0000	43419.441	14.918
7		Scenario 18	24 : Rule4Ne	101	450.0000	90.0000	43419.441	14.918
8		Scenario 19	24 : Rule4Ne	101	470.0000	70.0000	43419.441	14.918

Figure 28: Results of Process Analyzer in Scenario 1, 10% increasing case

Chapter 4: Experiments and Results

This chapter presents the experiments and results of the four different policies in which address either truck queueing or loader's scheduling policy or both, and the experiments and results of the production planning in the case of increasing number of incoming trucks. This chapter is divided into four different sections. The first section presents Truck queueing policy: Shortest Processing Time (of customer) policy, which will be referred as SPT. The second section present two policies for loader scheduling policy that is Shortest Traveling Time (of Loader) policy, which will be referred as STT policy, and Maximum Number in Queue policy, which will be referred as MaxQ policy. The third section presents Combined policy, which is the implementation of both SPT policy and STT policy on truck queueing and loader's scheduling policy. Finally, once the current system is improved with the suggested policy selected from the first three sections, the forth section presents an optimized level of production planning in the case of increasing number of incoming trucks in the system.

4.1 Truck queueing policy

In present state, the outbound logistics in the quarry has no queueing policy for incoming customer trucks. This means that the incoming trucks follow First in First out (FIFO) method in which the order of trucks receiving products depends on the arrival time of the truck. This can be translated that the first arrival truck receives the product before the second arrival truck and so on. The present state also disregards the size of truck, 6T, 10T or DT, and ignores the fact that different sizes of truck results in different processing time; the smaller the truck, the less processing time to fill up the dump box. Hence, the study presents SPT policy as Truck Queuing policy to be tested, which aims to reduce the average flow time that truck spent in the system by giving priority to truck that is required less processing time.

4.1.1 SPT policy

In order to improve the truck queuing issue of customer’s incoming trucks, the study aims to reduce average time spent of a truck in the system. This study found that SPT queueing method could minimize overall time spent of customer in the system by processing the less-processing-time customer first. Although SPT policy does not directly impact the operation efficiency of the system, it still helps increase the overall satisfactory of customer’s truck since it decreases average time spent of truck in the system and reduces the congestion of waiting trucks within the system. In addition to this, it is to be noted that because SPT policy does not directly change the operation efficiency of the system, the ending time of the last truck leaving the system each day remains unchanged. Exhibit 3 shows the comparison of the ending time of last truck in the system of the base model and SPT model.

By implementing SPT policy, the priority will be given to truck with lower processing time. It implies that when all the trucks waiting in queue, truck with higher priority (less processing time) will pass truck with lower priority (more processing time). Since 6T truck has the least processing time of 2:04 min, the highest priority is given to this type of truck. 10T and DT truck, on the other hand, has a processing time of 2:54 min and 4:41 min; thus, the priority is given as medium and low, respectively. Please note that this policy does not affect loader scheduling; hence, loading still serves trucks based on FIFO.

Since SPT policy deals with the arrival of trucks and not the operation of loader, only the order arrangement of trucks is focused. This means that after an empty truck finishes with the first weighing operation, the truck will be asked to move into the queueing line arranged base on the priority. Hence, when loader calls the truck in the queueing line to get serve, the truck will be released based in the queueing order and that the loader still serves trucks based on FIFO. Although there are three types of truck, 6T, 10T, and DT waiting for different product line, for conducting SPT policy and the simplicity of the model, the study will assume that once SPT model is implemented, there would be a single line for truck queueing and that the high priority truck will cut in front of the lower priority truck. This means that once the priority rule is implemented, the high priority 6T will surpass medium priority 10T which will surpass low priority DT. For instance, if there is 10T truck waits at the front of the queueing line, it will yield to 6T truck who just left the weighing station and let 6T truck cut in front of the line. Hence when loaders call in the truck, it will serve those who is at the front of the line first. Figure 32 represents how SPT model in Arena looks like whereas Figure 33 illustrates the logical flow of SPT policy.

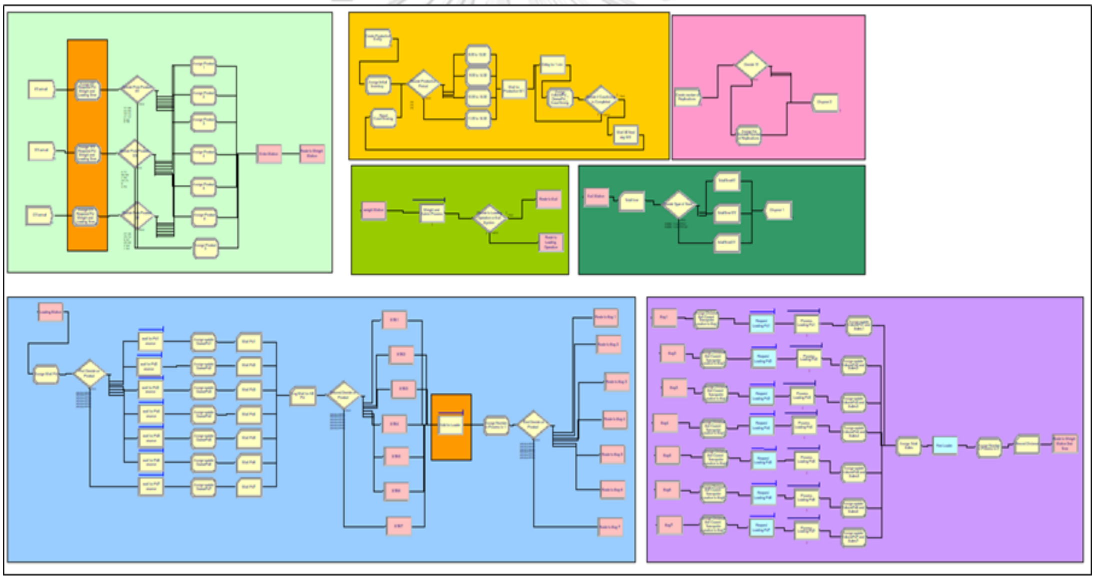

Figure 29: SPT model in Arena

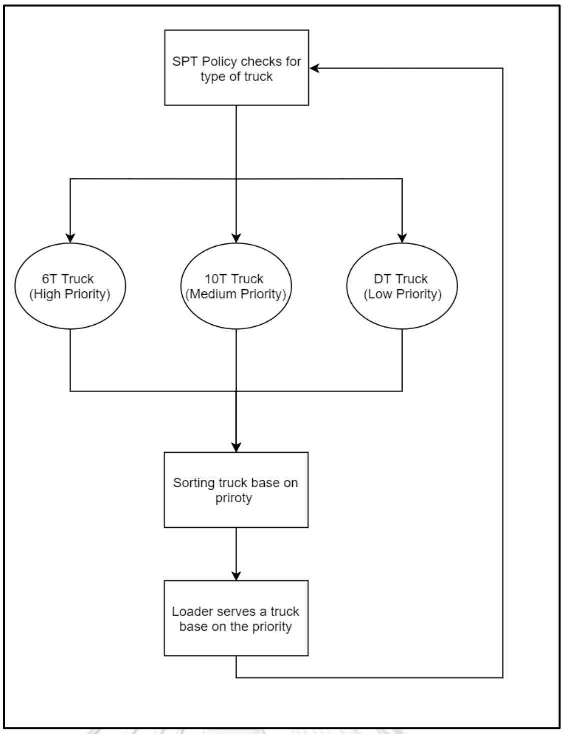

Figure 30: SPT Logical flow

4.1.1.1 SPT's logic

Following three figures, Figure 29 - Figure 31, confirm the logical idea of SPT that the higher priority should be giving to the entity with less processing time. Please note that for the simplicity of the comparison, three assumptions are made when comparing these figures. First, each block appears in the figures represent a time measurement of 1 second. Second, the loading time for 6T, 10T and DT is 1, 2 and 3 seconds, respectively. Third, these figures assume that all trucks received the product from the same stockpile (bay station); thus, the time it takes for a loader to travel within the same stockpile (Loader to Bay) represents the time loader to get ready to serve the next truck and assumes to be 1 second. Figure 29 shows that when the order priority is given to 6T, 10T, then DT truck, respectively, the average waiting time for truck is (0+2+5)/3 = 2.33 seconds and the average time spent for truck is (5+8+12)/ = 8.33 seconds. Figure 30 shows that when the order priority is given to different order, which is 6T, DT, then 10T, respectively, the average waiting time for truck is (0+2+6)/3 = 2.67 seconds and the average time spent for truck is (5+9+12)/3 = 8.67 seconds. Figure 31 shows that when the order priority is given to different order, which is DT, 10T, then 6T, respectively, the average waiting time for truck is (0+3+8)/3 = 3.67 seconds and the average time spent for truck is (7+11+14)/3 = 10.67 seconds. This proves that the higher priority of SPT should be given to those with lower processing time in order to reduce overall total time an entity spent in the system; hence, the priority will be given to 6T, 10T, then DT, respectively.

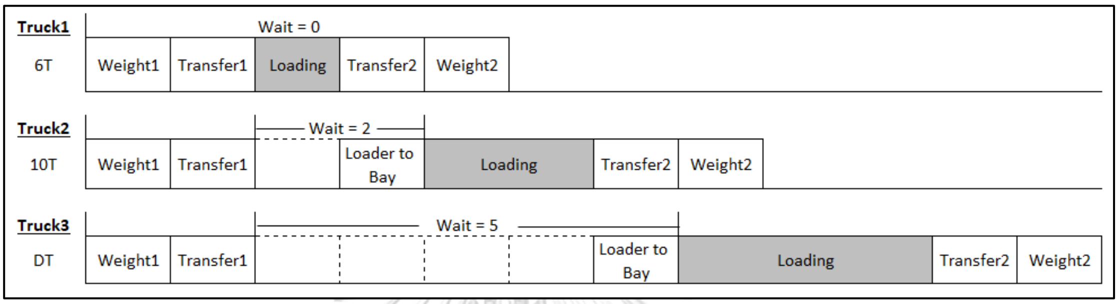

Figure 31: Truck order 6T > 10T > DT

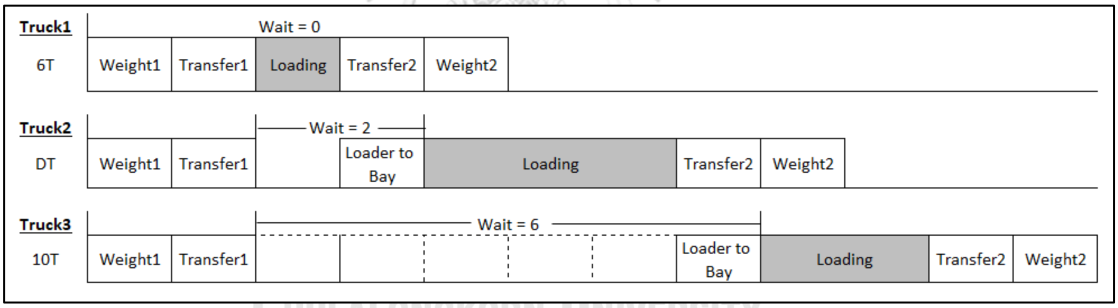

Figure 32: Truck order 6T > DT > 10T

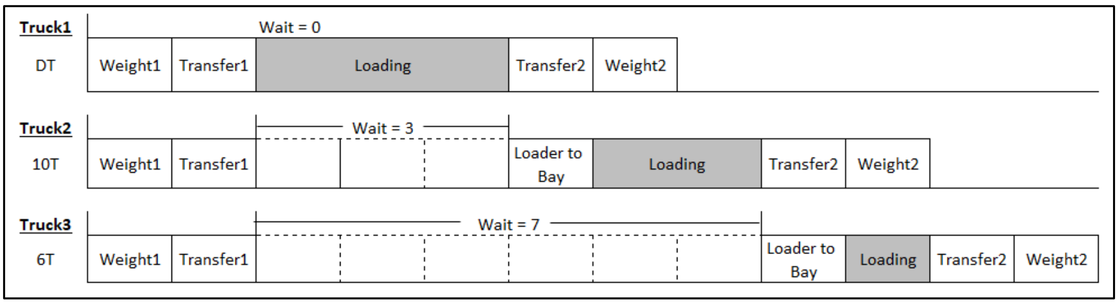

Figure 33: Truck order DT > 10T > 6T

4.1.1.2 Experiment and results of SPT policy

The study found that by applying SPT policy into Truck Queueing policy, the average flow time spent of a truck is now at 33.72 minutes which represents a reduction of 14.05% from 39.22 minutes in the base model whereas the monthly travel time of loader is reduced from 41889 seconds to 41261 seconds, which is equivalent to a reduction of 1.49% as seen in Table 16. In addition to this the average wait time for all products is reduced from 20.97 minutes to 17.55 minutes which represents a reduction of 16.31%.

Table 16: Result of SPT policy vs Base policy

Policy	Avg Flow Time of Truck (min)		Monthly Traveling Time of Loader (sec)		Avg Wait time for Products (min)	
	Average	Half Width	Average	Half Width	Average	Half Width
Base Case	39.22	5.58	41889.36	205.31	20.97	5.58
SPT	33.72	4.24	41261.89	228.87	17.55	4.28

4.1.1.3 Additional discussion of SPT policy

Although it can be said that SPT policy can reduce overall average flow time of truck from 39.22 minutes to 33.72 minutes and drives overall customer satisfaction since the two group of customer trucks (6T truck and 10T truck) in which accounts for 71% of overall trucks has less average flow time, not all customers are content. Table 17 indicates the further breakdown details of the average flow time of each type of truck comparing between Base and SPT case. It can be seen that by implementing SPT policy, both average flow time of 6T and DT decreases: 6T's reduces from 35.39 minutes to 25.57 minutes whereas 10T's reduces from 37.33 minutes to 30.54 minutes. Yet, the average flow time of DT increases by 6.94% from 47.38 minutes to 50.67 minutes.

Despite the fact that 21% of overall customer trucks, DT truck, has higher average flow time, SPT policy still gives a strong positive impact in the outbound logistics system since it greatly helps clear available space for the system. This means that SPT policy helps remove the congestion in the system since the policy releases more number of trucks out of the system faster by letting the less processing time trucks go first. This directly addresses the concern of the quarry with the limited physical serving space.

Table 17: Comparison of average flow time of each type of truck between Base and SPT policy

Policy	Average Flow time of each type of Truck (min)		
	6T	10T	DT
Base	35.39	37.33	47.38
SPT	25.57	30.54	50.67

4.2 Loader's scheduling policy

The study explores how loader scheduling can be better managed using two selected policies. Aside from help reduce an average flow time of truck in the system, improving loader scheduling also help decrease the travel time of loader, in which can lead to a better work efficiency of the loader. Hence, the study presents policy that could help loader better decide to which product stockpile the loader should move to in order to serve the next customer's truck. Since loader travels time from one stockpile to another stockpile is varied as can be seen in Table 9, the study also wants to find a policy that can also help reduce loader travel time. Figure 34 shows the physical location of product's stockpiles at the quarry.

Figure 34: Product's stockpiles at the end of each conveyor line

In order to choose which stockpile the loader should move to for the next product to be serve, factor such travel distance between stockpiles should be considered when proposing a policy. Loader's traveling time between stockpiles can be seen in Table 9. Therefore, the study tests and compares both average flow time of truck and monthly traveling time of loader in each policy in order to find the best policy for loader scheduling problem. The two policies presented to be tested for loader's scheduling policy includes STT and MaxQ policy.

4.2.1 STT policy

STT policy applies the idea of loader's shortest travel time in order to decrease loader's total travel time. Although the name implies to shortest traveling time, the logic behind STT policy in this study is more similar toward nearest distance of stockpile. This means that the policy asks loader to move to the product stockpile which locates next (closest) to the current one. Since there is only one loader serving in the system choosing to serve among seven products, STT policy simply asks loader to move in the predetermined order bases on the shortest traveling time.

Furthermore, the study found that while applying STT policy, a further investigation of the optimal number of batches allowed is also necessary in order to present the optimize solution. Allowing a batch of "n" trucks means that that if there happens to have multiple trucks who request the same product as to where loader is currently serving, loader will also serve those few more trucks depending on a designated batch size before moving to the next stockpile. Figure 35 represents how STT model in Arena look like whereas Figure 36 illustrates the general flow of STT policy.

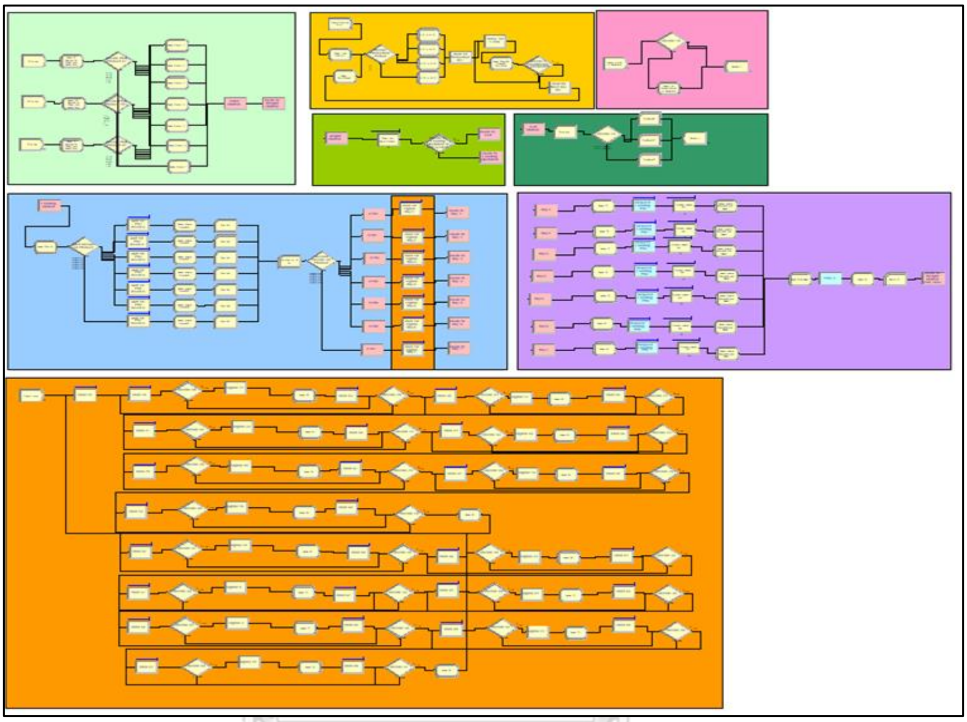

Figure 35: STT model in Arena

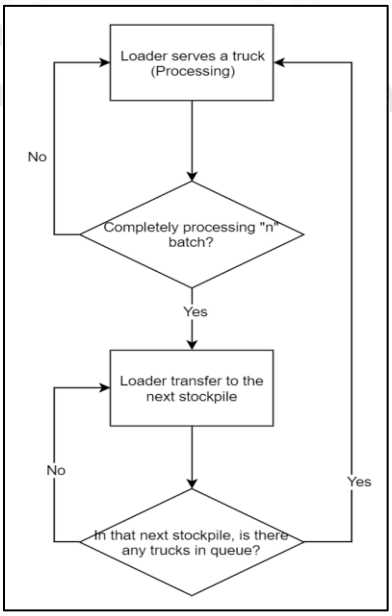

Figure 36: General flow of STT policy (loader's perspective)

4.2.1.1 The optimal number of batch selection for STT policy

In STT policy, the loader moves to the product stockpile that locates the nearest to the current position of the loader. By leveraging the policy, it can help loader avoid the non-value-added traveling action that resulted from a long distance traveling of a random travel between stockpiles. Hence STT policy applies shortest traveling time idea as a logic of reducing time traveling between stockpiles, as well as applies a batch of "n" trucks selection at the current stockpile as a logic of repeating the number of serving of the same product in order to reducing the number of traveling between stockpile. Please note that although batching trucks of the same product could help enhance loader scheduling policy since it would reduce less traveling distance of loader, repeating the action at one stockpile for a long time would not necessary yield a good result for overall system. Since average flow time of customer trucks consists of the waiting time for loader, by having a loader repeatedly serves at one particular stockpile for a long time would result in higher waiting time of customer trucks in other product lines. This would eventually drive up overall time customer spent in the system.

Please note that there is no particular pattern of average flow time of trucks by increasing number of batch setting as compared to the decreasing trend of loader's traveling time when increasing number of batch setting. This is due to the fact that there are also other factors aside from waiting time of loader that also affect the average flow time of truck e.g. waiting time for productions, waiting time for weighing station. Therefore, the study proposes to further investigate an optimal number of batch selection that would be allowed in STT policy in the two aspects of average flow time of truck as well as loader' traveling time.

Both average flow time of truck and monthly travel time of loader are selected as KPI to measure the performance of each batch setting. The smaller the number of the two KPIs, the higher chance that the batch setting would form optimal efficiency frontier. The optimal batch of "n" truck represents the maximum number of trucks that the loader can serve at the current stockpile before moving to the next stockpile.

Table 18: The results of a different number of batch selection for STT policy

Number of Batch(s)	Average Flow Time (min)	Traveling Time (sec)
1	38.28	39545.71
2	35.15	38781.54
3	36.09	38581.66
4	41.60	38497.70
5	38.36	38328.24
6	39.71	38315.81
7	41.72	38223.59
8	37.70	38151.73

Table 18 represents the result from running 101 replications using STT policy in Loader Scheduling policy and sets a range of batch number(s) of trucks from 1 to 8. From the table, although the two measured KPIs, average flow time of truck (min) and monthly travel time of loader (second), are presented in the table, the study gives higher weight consideration to the average flow time of truck KPI. This means that in when deciding between two optimal batch options that are productively efficient, the batch setting that results in smaller average flow time of truck would be preferable. For example, assumes that there are two optional batch options of "X" and "Y", in which "X" batch setting results in a smaller average flow time but higher traveling time whereas "Y" batch setting results in higher average flow time but smaller traveling time, the former batch setting of "X" is more preferable as compared to the later batch setting of "Y." In addition to this, it is to be noted that the 101 replications is automatically determined from the number of replica sub-model and that while running STT policy in Loader Scheduling part, FIFO method remains unchanged in Truck Queueing part.

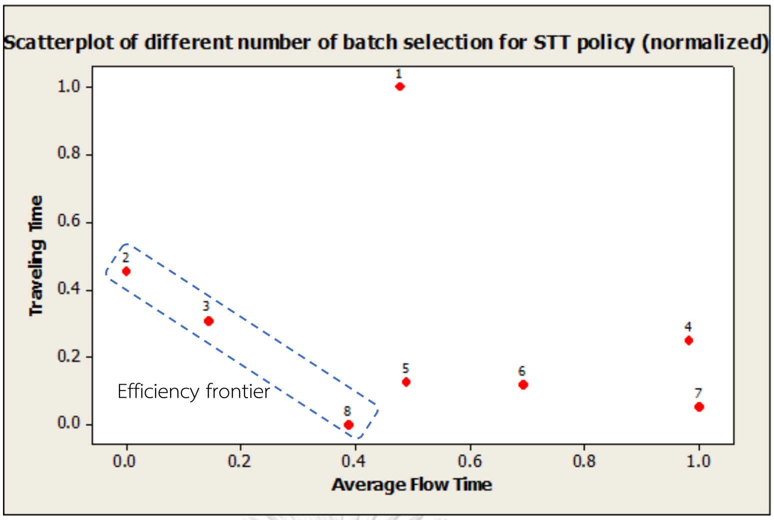

Figure 37: Scatter plot of different batch setting for STT policy (normalized)

Figure 37 represents normalized scatter plot derived from the information in Table 18 as well as where the efficiency frontier line is formed. All combinations of the two criteria (KPIs) that formed points on efficient frontier represent optimal choices that are productively efficient. This means that choosing one of those combination would display productive efficiency. Figure 37 shows that the batch setting of 2, 3, and 8 formed an efficient frontier and are productively efficient; however, the study chooses batch setting of 2 since the higher weight consideration is given to batch choice with lower average flowtime of truck KPI as compared to the choice with lower traveling time of loader KPI. Hence, the batch setting of 2 is selected as the optimized batch setting for STT policy.

4.2.1.2 Experiment and results of STT policy

Using an optimized number of batch selection of 2, result of STT policy can be seen in this section. Table 19 show that the total flow time when using STT policy is 35.15 minutes and loader's monthly travel time is 38781.54 seconds. This represents a reduction of 10.38% in total flow time and a reduction of 7.42% in loader's monthly travel time. However, the average wait time for all products in the case of STT policy increase from 20.97 minutes to 22.42 minutes which represents an increment of 6.92%. In addition this this, Table 20 shows a comparison of average flow time of each type of truck between base case and STT policy.

Table 19: Result of STT policy (batch setting of 2) vs Base policy

Policy	Avg Flow Time of Truck (min)		Monthly Traveling Time of Loader (sec)		Avg Wait time for Products (min)	
	Average	Half Width	Average	Half Width	Average	Half Width
Base Case	39.22	5.58	41889.36	205.31	20.97	5.58
STT (batch setting = 2)	35.15	5.28	38781.54	230.22	22.42	5.29

Table 20: Comparison of average flow time of each type of truck between Base and STT policy

Policy	Average Flow time of each type of Truck (min)		
	6T	10T	DT
Base	35.39	37.33	47.38
STT	30.81	32.82	44.40

4.2.1.3 Additional logic behind loader's traveling for STT policy

Even though by asking the loader to move to the product stockpile which locates the nearest to the current stockpile can reduce both average flow time of truck and monthly travel time of loader, there is still a chance that the further-away product will not get served. This event can occur particularly when there are ongoing queues at the nearby product stockpiles. When this happens, the loader will choose to move back and forth between those nearby product stockpiles and never leave to further stockpile. In order to adjust the policy into the real geographical setting and avoid the mentioned issue, the study modifies the policy by adding further constraint so that loader can move to all the product stockpiles without focusing in one particular queueing area. Hence, STT policy that is proposed in this study will ask the loader to move from one end to another end in designated direction and move back in reciprocating order. Please note that the policy is also assumed that the loader cannot return to the previous stockpile that it had served before the current stockpile. Therefore, it can be concluded that the pattern that the loader will move will be in the pattern of stockpile 1,2,3,4,5,6,7 then 7,6,5,4,3,2,1, repeatedly.

Following two figures, Figure 38 and Figure 39, help confirms why the pattern of the loader should be moved in order 1,2,3,4,5,6,7 then 7,6,5,4,3,2,1, repeatedly. Please note that for the simplicity of the comparison, three assumptions are made when comparing these figures. First, each block appears in the figure is equivalent to 1 second. Second, only 6T truck enters the system; loading time for 6T is 1 second. Third, loader's traveling time between stockpile is based from Table 8, i.e. loader takes 2 seconds to travel from Stockpile 5 to Stockpile 6, and takes 4 seconds to travel from Stockpile 5 to Stockpile 8, etc. Figure 38 shows that when the loader's order is set in ascending and descending order as proposed in STT policy, the average waiting time for truck is (0+3+7+8+12)/3 = 6.0 seconds and the average time spent for truck is (5+8+12+13+17)/5 = 11.0 seconds. Figure 39 shows that when the loader's order is at random, the average waiting time for truck is (0+5+9+13+18)/5 = 9.0 seconds and the average time spent for truck is (5+10+14+18+23)/5 = 14.0 seconds. This proves that the order of loader proposed in STT policy helps reduce the overall flow time an entity spent in the system.

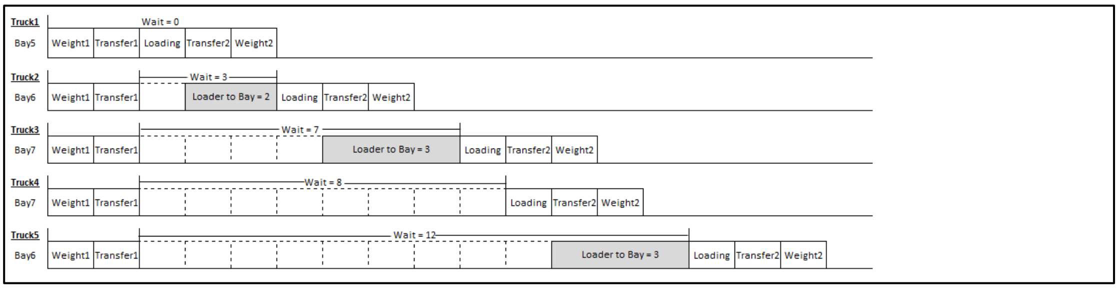

Figure 38: Order of loader's movement from Stockpile S5 > S6 > S7 > S7 > S6

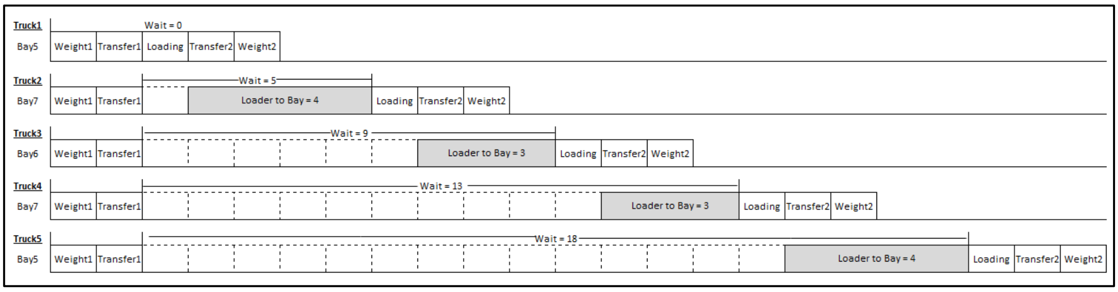

Figure 39: Order of loader's movement from Stockpile S5 > S7 > S6 > S7 > S5

4.2.1.4 The Loader's movement between stockpiles in STT policy

Earlier in this chapter, it shows that the optimized batch selection for STT policy is batch setting of 2. The batch of 2; hence, will be illustrated as an example of how loader moves between stockpiles. The following explains the movement in detail:

1. At the beginning of the system, loader will choose product stockpile that the first incoming truck requested. For example, let's assume product 4 as the first stockpile loader is stationed at.

2. Once the loader loads product onto the first truck, it will be determined whether there is another customer waiting in Product 4 stockpile. Because the batch of 2 is selected, if there is another customer waiting in Product 4 stockpile, loader is allowed to continue to serve the second customer who waits for the same product before moving to the next stockpile. On the other hand, if there is no customer waiting in Product 4 stockpile, once the first customer was served, the loader will move to the next stockpile right away.

3. Once the loader finished serving at the current Product 4 stockpile, the loader will consider to move to stockpile of Product 5, Product 6, then Product 7, in order. This bases on the closest time traveling from the current stockpile to the next stockpile. If the study assumes that there is no customer in Product 5

stockpile but there are customers in both Product 6 and Product 7 stockpile, then the Loader will skip Product 5 stockpile and move to Product 6 stockpile. Please noted that the loader chooses to move to Product 6 stockpile over Product 7 stockpile since Product 6 stockpile is closer to Product 4 stockpile as compared to Product 7's. And as mentioned in previous section, the study assumes that loader cannot move back to the previous stockpile such as Product 3 stockpile or keeps repeating perpetually serving at Product 4 stockpile.

4. The above illustrates how loader moves in the ascending order of product stockpiles that is to move in one direction from stockpile 1,2,3,4,5,6,7. Once the loader is at the end of product stockpile, which is Product 7 stockpile, it will move back in descending order of product stockpiles that is to move from stockpile 7,6,5,4,3,2,1. Please noted that at the end of product stockpile, Product 1 and Product 7 stockpile, loader will repeat the serving at that ending stockpile in order to equally serve every product stockpiles.

5. Once the loader served all customers in the system, the system is considered closed.

4.2.2 Max Q policy

Another policy that can also be applied into loader scheduling policy is Maximum Number in Queue policy (MaxQ policy). MaxQ policy utilizes the idea of identifying the bottleneck in a process and gives priority of work on that bottleneck area. The physical area constraint of the quarry limits the number of trucks that could be in the system at the same time. This implies that the higher queue in a particular product line results in the bottleneck of the system since it creates traffic and takes a lot of space. In MaxQ policy, loader will first serve the longest queue length of a product. To simply put, the system will analyze which product line has the longest queue at a current time and gives signal to loader to work on that product line. However, in order to avoid serving to one particular product that keeps having on-going trucks in a particular queue, a further investigation of the optimal number of batches allowed is necessary in order to present the optimize solution. This means that loader can only serve customers in the current product stockpile up to a batch of "n" trucks before forced to change to the new product stockpile. Figure 40 represents how MaxQ model in Arena looks like whereas Figure 41 illustrates the general flow of MaxQ policy.

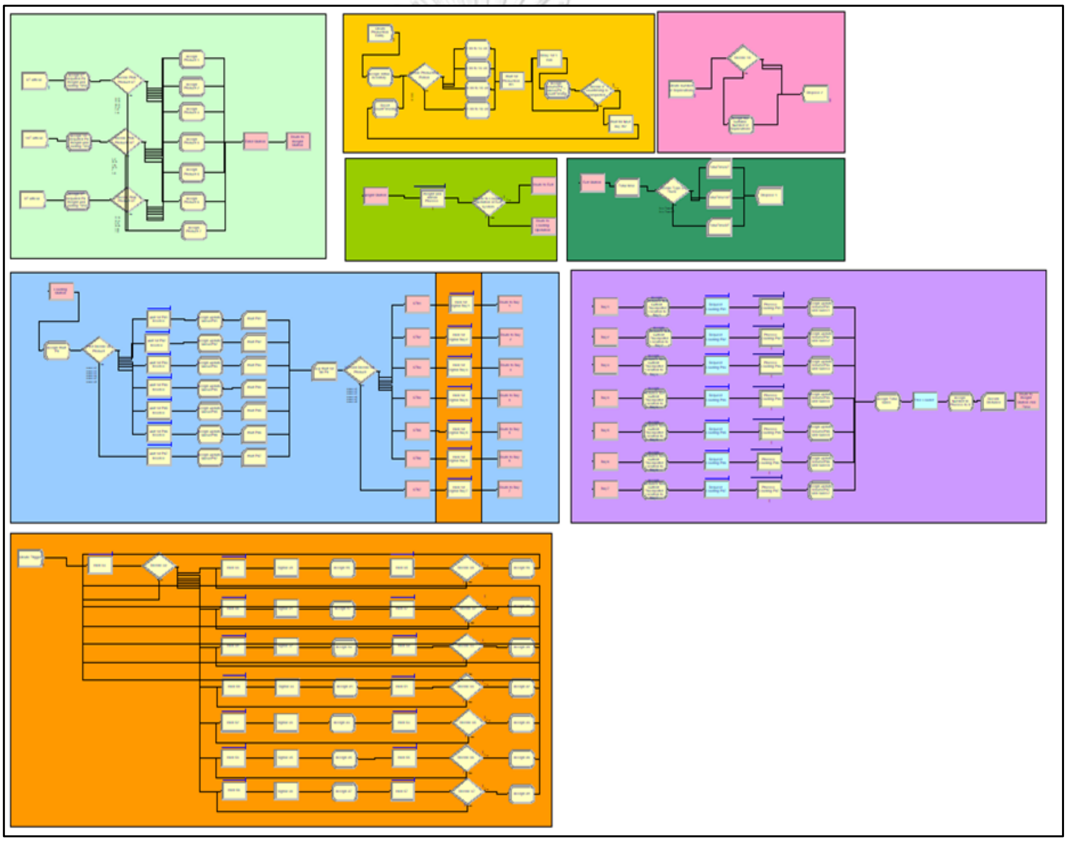

Figure 40: MaxQ model in Arena

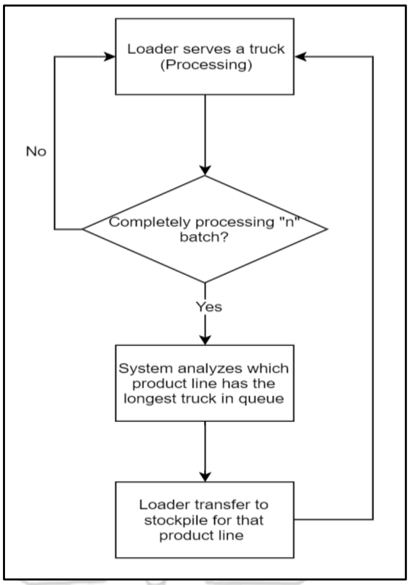

Figure 41: General flow of MaxQ Policy (Loader's perspective)

4.2.2.1 The Optimal Number of Batch Selection for MaxQ policy

In MaxQ policy, a batch of "n" truck selection is also needed to be determined by considering both average flow time of truck and monthly travel time of loader as two KPIs in order to avoid repeating the action at one particular stockpile for a long time. Like STT policy, the smaller the number of the two KPIs, the higher chance that the batch setting would form optimal efficiency frontier and that the study gives higher weight consideration to the average flow time of truck KPI.

The batch of "n" trucks means that the loader is allowed to serve up to "n" trucks that await in the same product line with the current serving product location. Applying the batch of "n" trucks into MaxQ policy means that the loader will determine which stockpile has the longest queue length of trucks and would serve those trucks up to "n" trucks in the longest queue before moving to the next longest queue in different stockpile. In addition to this, it is to be noted that although there is a decreasing trend of loader's traveling time when increasing number of batch setting, there is no particular pattern of average flow time of trucks resulted from an increase in number of batch setting.

Table 21: Results of a different number of batch selection for MaxQ policy

Number of Batch(s)	Average Flow Time (min)	Traveling Time (sec)
1	40.51	41035.84
2	37.22	40365.01
3	38.47	40234.88
4	40.38	40141.52
5	39.82	40135.90
6	42.42	40089.52
7	39.76	40079.34
8	39.76	40079.34

Table 21 shows the result from running 101 replications using MaxQ policy in Loader Scheduling policy and sets a range of batch number from 1 to 8. From the table, although the two measured KPIs, average flow time of truck (min) and monthly travel time of loader (second), are presented in the table, the study gives higher weight consideration to the average flow time of truck KPI. Like what the study did in STT policy, this means that in when deciding between two optimal batch options that are productively efficient, the batch setting that results in smaller average flow time of truck would be preferable. It is to be noted that while running MaxQ policy in Loader Scheduling part, FIFO method remains unchanged in Truck Queueing part.

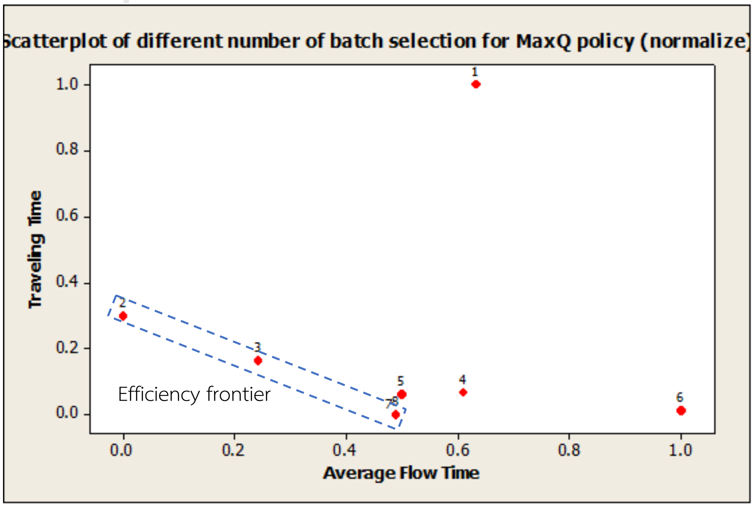

Figure 42: Results of a different number of batch selection for MaxQ policy (normalized)

Figure 42 represents normalized scatter plot derived from the information in Table 21 as well as where the efficiency frontier line is formed. All combinations of the two criteria (KPIs) that formed points on efficient frontier represent optimal choices that are productively efficient. This means that choosing one of those combination would display productive efficiency. Figure 42 shows that the batch setting of 2, 3, 7, and 8 formed an efficient frontier and are productively efficient; however, the study chooses batch setting of 2 since the higher weight consideration is given to batch choice with lower average flowtime of truck KPI as compared to the choice with lower traveling time of loader KPI. Hence, the batch setting of 2 is selected as the optimized batch setting for STT policy. Please note that both batch setting of 7 and 8 results in the same average flow time and monthly traveling time since there is no queue that is longer than seven trucks.

4.2.2.2 Experiment and results of MaxQ Policy

Using an optimized number of batch selection of 2, results of MaxQ policy can be seen below. Table 22 show that the total flow time when using MaxQ policy is 37.22 minutes and loader's monthly travel time is 40365.01 seconds. This represents a reduction of 6.21% in total flow time and a reduction of 3.64% in loader's monthly travel time. However, the average wait time for all products in the case of MaxQ policy increase from 20.97 minutes to 24.54 minutes which represents an increment of 17.02%. In addition to this, Table 23 shows a comparison of average flow time of each type of truck between base case and MaxQ policy.

Table 22: Result of MaxQ policy (batch setting of 2) vs Base policy

Policy	Avg Flow Time of Truck (min)		Monthly Traveling Time of Loader (sec)		Avg Wait time for Products (min)	
	Average	Half Width	Average	Half Width	Average	Half Width
Base Case	39.22	5.58	41889.36	205.31	20.97	5.58
MaxQ (batch setting = 2)	37.22	6.19	40365.01	192.97	24.54	6.21

Table 23: Comparison of average flow time of each type of truck between Base and MaxQ policy

Policy	Average Flow time of each type of Truck (min)		
	6T	10T	DT
Base	35.39	37.33	47.38
MaxQ	32.69	33.57	47.57

4.2.2.3 The Loader Movement between stockpiles in MaxQ policy

In MaxQ policy, system will analyze the queue length in all product lines before giving signal to loader to move to serve the longest queue. Since the batch setting of 2 is an optimal number for MaxQ policy, once the loader finish serving up to two trucks in that product line, the system will force the loader to leave the current stockpile and move to the next longest queue length in the system. For example, with the batch setting of 2, let's assumes that the loader is currently serving two trucks at product stockpile 4. Once the loader finishes serving the second customer truck, the system will evaluate the longest queue in the system. With the assumption that the loader cannot repeat serving at the current product stockpile, the loader will be forced to move to the product stockpile with the longest queue, which is not at current product stockpile (in this case stockpile 4). Assumes that both product stockpile 4 and product stockpile 2 have the longest queue length of 5 customers, the system will force the loader to move to product stockpile 2 and serves up to two customers before repeating the cycle of evaluating the next longest queue.

4.3 Combined policy (SPT & STT policy)

When comparing two policies under loader's scheduling policy in section 4.2.1 and section 4.2.2, the study found that STT policy results in a better improvement for both two KPIs as compare to MaxQ policy. Therefore, the study chooses STT policy to be recommended in the loader's scheduling problem. Hence, in Combined policy STT policy will be selected for loader's scheduling policy whereas SPT will be selected for truck queuing policy.

The Combined policy helps improving both truck queueing and loader scheduling part. As the name suggested, The Combine policy is a combination that selected best policy from truck queueing policy (SPT) and loader scheduling policy (SPT). Figure 43 represents how Combined Policy model in Arena looks like. The figure highlights the orange area in which additional priority attribute was created in the modules.

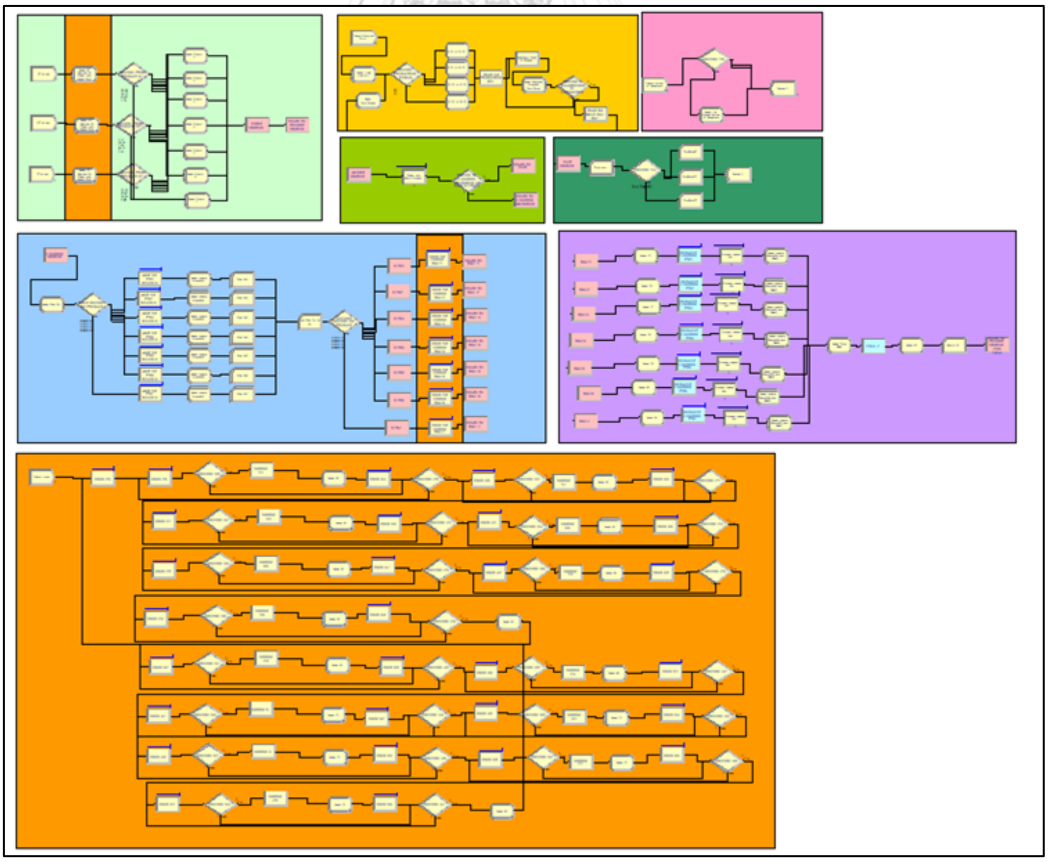

Figure 43: Combined policy model in Arena

4.3.1 Experiment and results of Combine policy

After applied the Combined policy into the model, the study found that the average flow time decreases to 26.54 minutes and the monthly travel time of loader decreases to 38731.24 seconds as can be seen in Table 24. When compared to the base model without the implementation of the policy, the Combine policy help reduced the total flow time and loader's monthly travel time by 12.68 minutes and 3158.12 seconds. This represents 32.33% reduction in total flow time and 7.54% reduction in loader's monthly traveling time. In addition to this, the average wait time for all products decreases from 20.97 minutes to 13.59 minutes which represents a reduction of 35.19%. In addition to this, Table 25 shows a comparison of average flow time of each type of truck between base case and Combined policy.

Table 24: Result of Combined policy (SPT & STT) vs Base policy

Policy	Avg Flow Time of Truck (min)		Monthly Traveling Time of Loader (sec)		Avg Wait time for Products (min)	
	Average	Half Width	Average	Half Width	Average	Half Width
Base Case	39.22	5.58	41889.36	205.31	20.97	5.58
Combined (SPT & STT)	26.54	5.57	38731.24	208.42	13.59	5.59

Table 25: Comparison of average flow time of each type of truck between Base and Combined policy

Policy	Average Flow time of each type of Truck (min)		
	6T	10T	DT
Base	35.39	37.33	47.38
Combined	26.54	27.19	32.82

4.4 Production planning for a future change in demand

With the implementation of Combined policy, the study further investigates different scenarios in the case of increasing number of customers in order to help the quarry better prepare for a better decision making and future production planning.

Throughout the production planning analysis, the Combined policy (SPT and STT) of batch selection of 2 is chosen as a base policy since it yields the best improvement for outbound logistics operations. This means that throughout the production planning analysis, Combined policy will automatically be implemented into the outbound logistics model and that the only varied part will be the change in demand in different scenarios.

Assumes that the external factors such as weather and climate change do not significantly impact the quarry operation, the quarry then can adjust the production level by increasing the amount of average daily production hours. This means that the adjusted production model can handle higher number of customers accordingly. Hence, this study wants to further analyze scenarios, in which only customer forecast is varied and that the quarry has already implemented Combine policy into both truck queueing and loader scheduling operation, to see how production can be better plan using the model that was built. In order to analyze and plan future management, the study presents selected five scenarios of the increasing number of trucks by 10%, 20%, 30%, 40%, and 50%. Please note that at the current level of demand, there are 1,467 trucks for 6T trucks, 388 trucks for 10T trucks, and 766 trucks for DT trucks.

Process Analyzer is applied to the simulation model in order to calculate the appropriate production run time starting the production hour at 08:00 with the run setup of 101 replications. The logic to determine the optimal amount of production run time is that at “the hour” that the sales amount becomes stable as appeared in Process Analyzer, “the hour” of daily production run time would yield the adequate amount of products. This means that “the hour” represents the appropriate daily production run time that is sufficient to supply products for that set of customers. Since the study uses monthly production plan as simulation time frame, the amount of hours would represent the average hour the production should run daily for a month long period. The following represents the analysis of five scenarios of the increasing number of customers.

4.3.1 Scenario 1: 10% increase in monthly incoming truck

By increase number of incoming trucks 10%, the study found that with the current production hours of 330 minutes (5.5 hours), the production amount is not sufficient with this level of demand. This results in the average flow time of 113.28 minutes, as can be seen in Table 26. In addition to this, the value of average wait time for productions of 99.23 minutes confirms that the high average flow time is caused by the insufficient production amount.

Table 26: Comparison of before and after production run time adjustment in the case of 10% increasing

Percentage increase in incoming trucks	Production time (min)	Avg flow time of trucks (min)	Avg wait time for productions (min)	Monthly traveling time of loader (sec)
10%	330	113.28	99.23	41630.52
10%	430	14.92	0.00	42669.98

In order to address the production issue, Process Analyzer is used in order to identify the appropriate average production run time. Figure 44 shows that the number of total sales (Response: Total sales) reaches a stable number of 43419 tons at the production time (Controls: Working) of 430 minutes. This can be translated as the appropriate production hour for the 10% increasing in monthly incoming customer case is 430 minutes.

		Scenario Properties			Controls		Responses	
	S	Name	Program File	Reps	Working	WaitforFree	Total sales	Total time
1		Scenario 12	24 : Rule4Ne	101	330.0000	210.0000	41690.282	113.285
2		Scenario 13	24 : Rule4Ne	101	350.0000	190.0000	42566.195	58.251
3		Scenario 14	24 : Rule4Ne	101	370.0000	170.0000	43138.713	25.117
4		Scenario 15	24 : Rule4Ne	101	390.0000	150.0000	43372.617	16.758
5		Scenario 16	24 : Rule4Ne	101	410.0000	130.0000	43411.760	15.126
6		Scenario 17	24 : Rule4Ne	101	430.0000	110.0000	43419.441	14.918
7		Scenario 18	24 : Rule4Ne	101	450.0000	90.0000	43419.441	14.918
8		Scenario 19	24 : Rule4Ne	101	470.0000	70.0000	43419.441	14.918

Figure 44: Results of Process Analyzer in Scenario 1, 10% increasing

The new result in the case of 10% increasing in number of trucks after adjusted the production run time to 430 minutes can also be seen Table 26. It shows that by adjusting the production run time to 430 minutes, a new average flow time is 14.92 minutes with no average wait time for productions. The 0.00 minute of average wait time for productions helps confirm that the new production run time is sufficient to supply the amount of products for the amount of forecasted customers and that the system could still accept higher number of incoming trucks. Similarly, the same process to identify and analyze appropriate production run time is also applied into the case of 20%, 30%, 40% and 50% increase in monthly incoming trucks and result is summarized in Table 27.

Table 27: Different Scenarios after the implementation Combined Policy

Different Scenarios after the implementation Combined Policy				
Percentage increase in incoming trucks	Production time (min)	Avg flow time of trucks (min)	Avg wait time for productions (min)	Monthly traveling time of loader (sec)
0%	330	26.54	13.59	38731.24
10%	430	14.92	0.00	42669.98
20%	470	17.20	0.00	46076.46
30%	510	20.44	0.00	49884.51
40%	540	25.81	0.40	54140.25
50%	540	34.75	1.96	58316.65

4.3.2 Scenario 2: 20% increase in monthly incoming truck

	Scenario Properties				Controls		Responses	
	S	Name	Program File	Reps	Working	WaitforFree	Total sales	Total time
1		Scenario 1	4 : Rule4Ne	101	330.0000	210.0000	43945.416	251.306
2		Scenario 2	4 : Rule4Ne	101	350.0000	190.0000	45009.400	169.416
3		Scenario 3	4 : Rule4Ne	101	370.0000	170.0000	45809.427	108.443
4		Scenario 4	4 : Rule4Ne	101	390.0000	150.0000	46599.972	51.002
5		Scenario 5	4 : Rule4Ne	101	410.0000	130.0000	47023.569	28.285
6		Scenario 6	4 : Rule4Ne	101	430.0000	110.0000	47122.910	19.052
7		Scenario 7	4 : Rule4Ne	101	450.0000	90.0000	47182.075	17.198
8		Scenario 8	4 : Rule4Ne	101	470.0000	70.0000	47161.219	17.124
9		Scenario 9	4 : Rule4Ne	101	490.0000	50.0000	47161.219	17.124

Figure 45: Results of Process Analyzer in Scenario 2, 20% increasing case

Figure 45 shows the result of Process Analyzer addressing the hours of production run in the case of increase in incoming trucks 20%. It can be seen that the number of total sales (Response: Total sales) reaches a stable number of 47161 tons at the production time (Controls: Working) of 470 minutes. This can be translated as the appropriate production hour for the 20% increasing number of customer case is 470 minutes.

The new result for the case of 20% increasing in monthly incoming trucks after adjusted the production run time to 470 minutes can be seen Table 27. It shows a new average flow time of 17.20 minutes with no average wait time for productions. The 0.00 minute of average wait time for productions helps confirm that the new production run time is sufficient to supply the amount of products for the amount of forecasted customers and that the system could still accept higher number of incoming trucks.

4.3.3 Scenario 3: 30% increase in monthly incoming truck

	Scenario Properties				Controls		Responses	
	S	Name	Program File	Reps	Working	WaitforFree	Total sales	Total time
1		Scenario 1	4 : Rule4Ne	101	330.0000	210.0000	46234.229	361.973
2		Scenario 2	4 : Rule4Ne	101	350.0000	190.0000	47161.758	288.026
3		Scenario 3	4 : Rule4Ne	101	370.0000	170.0000	47962.960	223.721
4		Scenario 4	4 : Rule4Ne	101	390.0000	150.0000	48993.621	159.900
5		Scenario 5	4 : Rule4Ne	101	410.0000	130.0000	49941.370	91.560
6		Scenario 6	4 : Rule4Ne	101	430.0000	110.0000	50615.456	44.794
7		Scenario 7	4 : Rule4Ne	101	450.0000	90.0000	51092.370	25.570
8		Scenario 8	4 : Rule4Ne	101	470.0000	70.0000	51184.619	21.270
9		Scenario 9	4 : Rule4Ne	101	490.0000	50.0000	51161.994	20.567
10		Scenario 10	4 : Rule4Ne	101	510.0000	30.0000	51174.857	20.444
11		Scenario 11	7 : Rule4Ne	101	530.0000	10.0000	51174.857	20.444

Figure 46: Results of Process Analyzer in Scenario 3, 30% increasing case

Figure 46 shows the result of Process Analyzer addressing the hours of production run in the case of increase in incoming trucks 30%. It can be seen that the number of total sales (Response: Total sales) reaches a stable number of 51179 tons at the production time (Controls: Working) of 510 minutes. This can be translated as the appropriate production hour for the 20% increasing number of customer case is 510 minutes

The new result for the case of 30% increasing in monthly incoming trucks after adjusted the production run time to 510 minutes can be seen Table 27. It shows a new average flow time of 20.44 minutes with no average wait time for productions. The 0.00 minute of average wait time for productions helps confirm that the new production run time is sufficient to supply the amount of products for the amount of forecasted customers and that the system could still accept higher number of incoming trucks.

4.3.4 Scenario 4: 40% increase in monthly incoming truck

	Scenario Properties				Controls		Responses	
	S	Name	Program File	Reps	Working	WaitforFree	Total sales	Total time
1		Scenario 1	4 : Rule4Ne	101	330.0000	210.0000	48445.526	461.000
2		Scenario 2	4 : Rule4Ne	101	350.0000	190.0000	49216.295	405.733
3		Scenario 3	4 : Rule4Ne	101	370.0000	170.0000	50407.105	341.193
4		Scenario 4	4 : Rule4Ne	101	390.0000	150.0000	51465.097	281.941
5		Scenario 5	4 : Rule4Ne	101	410.0000	130.0000	52167.981	207.304
6		Scenario 6	4 : Rule4Ne	101	430.0000	110.0000	53169.617	138.399
7		Scenario 7	4 : Rule4Ne	101	450.0000	90.0000	54070.576	87.836
8		Scenario 8	4 : Rule4Ne	101	470.0000	70.0000	54690.754	46.729
9		Scenario 9	4 : Rule4Ne	101	490.0000	50.0000	54992.771	29.991
10		Scenario 10	4 : Rule4Ne	101	510.0000	30.0000	55072.863	26.320
11		Scenario 11	4 : Rule4Ne	101	530.0000	10.0000	55126.082	25.811
12		Scenario 12	10 : Rule4Ne	101	540.0000	0.0000	55135.399	25.808

Figure 47: Results of Process Analyzer in Scenario 4, 40% increasing

Figure 47 shows the result of Process Analyzer addressing the hours of production run time in the case of increase in incoming trucks 40%. It can be seen that the number of total sales (Response: Total sales) reaches a stable number of 55315.40 tons at the production time (Controls: Working) of 540 minutes. This can be translated as the appropriate production hour for the 50% increasing number of customer case is 540 minutes, which is the maximum number of the hours run length for the quarry. However, the maximum run time of 540 minutes does not mean that the system can no longer accept more incoming customers. Scenario 5 will later illustrate the case of 50% increase in the number of customer.

The new result for the case of 40% increasing in monthly incoming trucks after adjusted the production run time to 540 minutes can be seen Table 27. It shows a new average flow time of 25.81 minutes with 0.40 minutes average wait time for productions. It is to be noted that, the close-to-zero average wait time for productions of, 0.40 minutes, still indicates that the system could still accept higher number of incoming trucks with this full production run length; however the increase in number of customers beyond this point may result in higher wait time which could lead to higher flow time. This will be further discussed in Scenario 5.

4.3.5 Scenario 5: 50% increase in monthly incoming truck

The result from Scenario 4, it can be seen that the close-to-zero average wait time for production of all products (0.40 minutes) indicates that the system could still accept higher number of customers with the full production run time of 540 minutes. Hence, the study selects an 50% increasing number of customers case to be further investigated.

With the maximum run time of 540 minutes for the case of 50% increasing in monthly incoming trucks, it can be seen that the average wait time for productions increase to 1.96 minutes with a new average flow time of 34.75 minutes as can be seen in Table 27. The increase in number of average wait time for productions (non-zero value) shows that the highest number of increases in customer for the system can be limited to only 50% increase of monthly incoming trucks since beyond that it would result in a higher waiting time. Therefore, in order to avoid the waiting time issue, the quarry needs to adjust its production accordingly.

4.3.6 The utilization of loader in the case of increases in incoming truck

The utilization of the loader is calculated from the amount of daily work the loader does versus the actual operating time of 9 hours a day. The amount of work the loader does include both loading operations and transferring action between stockpiles. Figure 48 summarizes the utilization of loader given the increases in number of incoming trucks. It can be seen that the higher the number of incoming trucks, the higher utilization loader has since the loader has to serve more customers. The loader’s utilization given different incoming trucks are 61.60% at the current set of customers; 65.48% given the 10% increase of incoming trucks; 68.85% given the 20% increase of incoming trucks; 71.94% given the 30% increase of incoming trucks; 74.99% given the 40% increase of incoming trucks, and 77.79% given the 50% increase of incoming trucks. The 77.79% of the loader’s utilization for the 50% increase of incoming trucks shows that beyond this set of incoming trucks, the study recommends the quarry to get additional loader. However, the additional loader should be further studied in terms of economic benefits.

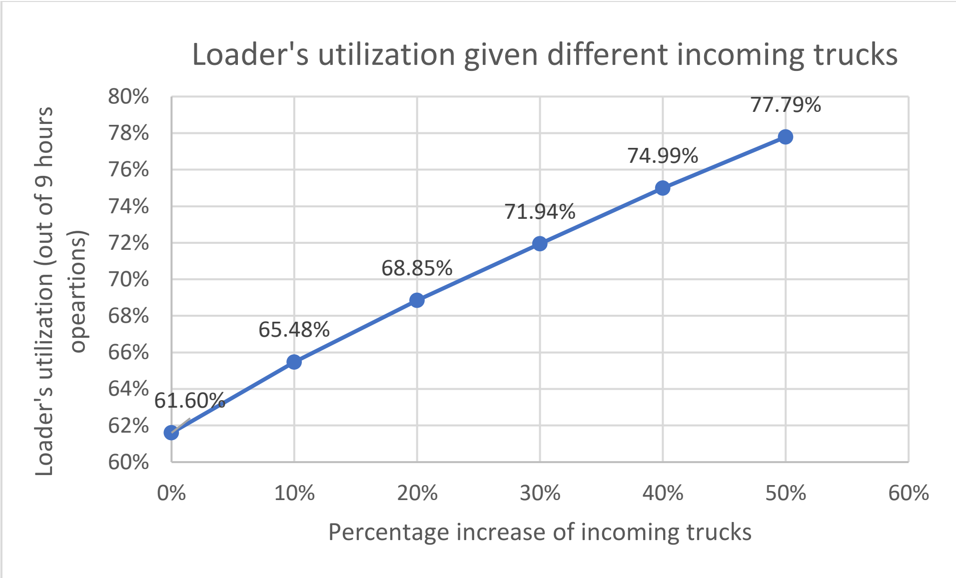

Figure 48: Loader's utilization given different incoming trucks

Chapter 5: Conclusions and recommendations

Hence, this chapter summarizes the results and the analysis that this study presented in the previous chapters and also concludes the suggestions that could be used in the outbound logistics in the quarry.

5.1 Problem statement and methodology

The goal of this study is to identify and recommend policy that can help improves the operations of logistics outbound of the quarry by reducing both average flow time and loader's traveling time. The reduction in the two criteria allow the system to be able to serves higher number of incoming customers within the limited physical space. This implies that by implementing the policy into the current system, the quarry would be able to serve more number of incoming customers, which align with the growing number of demand within the province, using the same using the same available resources. In addition to this, by having a lower average flow time a customer truck spent in the system, it would also lead to a higher customer satisfaction overall.

The limitation of the time constraint and the availability of the data greatly impacts the base assumptions that were use while building the model. This implies that the nature of the model is close to the behavior of customer and production during the two months of the data collection period, in which may not entirely represent high seasonal production during October – April nor entirely represent low seasonal production during July-September. By collecting data during different time period may change the result of the study.

5.2 Loader scheduling and truck queueing policies

The study aims to improve the current outbound logistics for the quarry by presenting different policies that could be applied into the real situation. There are two main parts that a testing policy could be implemented into. First is the truck queueing part and second is loader scheduling part. In this study, four policies were implemented into the model. The first one focuses on improving truck queueing part (SPT policy); the next two focus on improving loader scheduling part (STT and MaxQ policy); and the last one focuses on improving both truck queueing and loader scheduling part (Combined policy). The simulation result for all policies can be seen in Table 28.

Table 28: Simulation results for different testing methods in each policy

Policy	Number of Batch Setting	Avg Flow Time of Truck (min)	Details of Average Flow Time of each type of truck (min)			Monthly Traveling Time of Loader (sec)	Avg Wait time for Products (min)
			6T	10T	DT		
Base model	-	39.22	35.39	37.33	47.38	41889.36	20.97
Truck queuing policy							
SPT	-	33.72	25.57	30.54	50.67	41261.89	17.55
Loader scheduling policy							
STT	2	35.15	30.81	32.82	44.40	38781.54	22.42
MaxQ	2	37.22	32.69	33.57	47.57	40365.01	24.54
Combine policy							
SPT & STT	2	26.54	23.05	27.19	32.82	38731.24	13.59

This study investigates methods that can help minimize average flow time of a truck and loader's monthly traveling time of a loader in order to improve outbound logistics system in a quarry business. In Truck Queueing policy, the study recommends Shortest Processing Time (of Customer) policy (shorten as SPT policy), whereas in Loader Scheduling policy, the study recommends Shortest Traveling Time (of Loader) policy (shorten as SPT policy). By combining the best policy from both Truck Queuing and Loader Scheduling policy, the study also found that the Combined policy, a combination of both SPT and STT Policy, helps reduce 32.33% of the average flow time from 39.22 min to 26.54 min and reduce 7.53% of the loader's monthly traveling time from 41889.36 seconds to 38731.24 seconds. The result shows that the Combined policy best helps improve both average flow time of truck and monthly traveling time of loader, which result in a better operational efficiency, as compared to other proposed policies.

5.2.1 Advantage and limitation of each policy

5.2.1.1 SPT policy

The different in sizes of 6T, 10T, DT truck yields different processing time. Hence, SPT policy is based on the priority that it gives to different type of trucks. The high priority is given to 6T trucks that has the lowest processing time, followed by medium priority for 10T and low priority to DT, respectively. By doing so, the system can lower the average flow time truck spent in the system as a whole since the system focuses on serving the lowest processing time trucks. This means that SPT policy can help drives better overall customer satisfaction since the two group of customers (6T and 10T trucks), in which accounts for 71% of overall trucks, has less average flow time as compared to the base case; 6T truck's average flow time reduces by 38.40% from 33.39 minutes to 25.57 minutes and 6T truck's average flow time reduces by 22.23% from 27.33 minutes to 30.54 minutes. However, the trade off from SPT policy is that the average flow time of high processing time customer, DT truck, increases by 6.94% from 47.38 minutes to 50.67 minutes.

In term of applying SPT policy into the current outbound logistics system, SPT can still gives a strong positive impact to the system since it greatly helps address the concern of space limitation i.e. clear available space for the system. This means that SPT policy helps remove the congestion in the system better since the policy releases trucks out of the system faster by letting the less processing time trucks go first. This directly addresses the concern of the quarry with the limited physical serving space.

On the other hand, the downside of applying SPT policy in the real system is concern with the possible of how to put the rearranging queue into a practice without having complaints from the customers since the system must rearrange queue in the queueing line by letting the higher priority trucks cut in front of the line. The quarry also needs to set up a new waiting area for all trucks to be called in order to rearrange queuing order and implement queuing system that will notify customer trucks with higher priority to enter the queue line first. The quarry also might have to come up with a way to compensate DT customer for the higher time spent e.g. set up certain special time slot or pre-appointment just for DT trucks.

5.2.1.2 STT policy

STT policy applies the idea of the shortest traveling time of loader. Hence, the loader is a key player to choose the nearest stockpile, in which there are customers waiting in line, to serve. By using STT policy, the system can reduce the monthly travel time of loader as well as lower the average flow time of truck. As compared to SPT policy, STT policy is more suitable for limited physical space of the quarry since no set up of a new waiting area is required. Since STT policy addresses on loader's operation, the loader will move to the designate order of stockpile and serve up to 2 trucks (optimize batch setting is 2 trucks). The loader will also skip the line if there is no customer waiting in that next line.

The limitation of this STT policy is concerned with the possible of applying batching when serving customer trucks. Since loader is asked to serve two customers at each stockpile before moving to the next pre-determined stockpile, there is a chance that the loader will refuse to follow the rule and, instead, serve bases on what it seems to be a fitted. In order to apply STT policy, the quarry needs to explain the rule to the loader and ask the loader to follow the pre-determined order. In addition to this, the quarry also needs to make sure that there is enough area for loader to moves freely at all time between product stockpiles. This means that no customer truck is allowed to go near the loader and that customer truck can only wait at the assigned waiting area and assigned serving area.

5.2.1.3 MaxQ policy

MaxQ policy utilizes the idea of identifying the bottleneck in a process and gives priority of work on that bottleneck area first. Hence, the loader is a key player to choose the next stockpile that has the longest queue length of a product. Like STT policy, MaxQ policy is more suitable for limited physical space of the quarry since no set up of a new waiting area is required. Since MaxQ policy addresses on loader's operation, the system will evaluate queue in each product stockpile and ask the loader to move to stockpile with the longest queue. The loader will also ask to not repeat the same current product stockpile that it just finished serving.

The limitation of applying MaxQ policy into the real system concerns with the evaluation system that determine queue length of customers in each product stockpiles. Since the evaluation needs to be close to real time and that loader has to follow the order instruction, further development of the system and additional training is necessary. In addition to this, the quarry also needs to make sure that there is enough area for loader to moves freely at all time between product stockpiles. This means that no customer truck is allowed to go near the loader and that customer truck can only wait at the assigned waiting area and assigned serving area.

Although MaxQ policy can help address both average flow time of truck and loader's traveling time, the experiment result is inferior to that of STT policy in both aspects. This could result from the physical location of the popular product that is far from one another. This means that for MaxQ policy to work best, the popular products needs to be close by one another since it would require less time for loaders to travel back and forth. However, in reality, with the nature of quarry production line, it is impossible to adjust the location of each product stockpile since each product line was predetermined from when the quarry machine was installed.

5.3 Production planning for a future change in demand

With the implementation of Combined policy, the study further investigates different scenarios in the case of increasing number of incoming trucks in order to help the quarry prepare for a better decision making for future production planning. Five different scenarios in different number of incoming trucks were pre-set in an increment of 10%. The appropriate average daily production run time for each scenario is recommended to be applied for the production planning subjected to a monthly time frame.

Chapter 4 shows the experiment of production run time in different scenario when there is an increase in number of incoming trucks. Table 27 summarizes the amount of production run time that should be adjusted accordingly based on the forecast of incoming demands. The base case of 0% increase in incoming customers shows that even though the Combined policy help decrease the average flow time of trucks from 39.22 minutes to 26.54 minutes, there is still a room for an improvement regarding to production since average wait time for productions is 13.59 minutes, indicating that half of the total flow time is due to the wait of productions. Therefore, in the case of an increase in number of incoming trucks of 10%, 20%, 30%, 40% and 50%, different production run time is recommended in order to solve the issue of high average wait time for productions. It can be concluded that 540 minutes is the maximum production run time that the system can have and 50% increase in number of customers is a maximum number of incoming trucks in a month that the study thinks that the current system could handle after the implementation of *Combined policy*.

5.4 Future work

This study only proposes four policies that help address truck queueing and/or loader scheduling for policies analyzing part and applied the best policy of the four into the production planning for future change in demand. It is to be noted that the study assumes four production patterns with a probability of occurring of 0.25 for policies analyzing part while assumes only one production pattern in which starts at 8:00 for production planning part. The future work can be further explored into these following:

- Further explore additional policies on truck queueing part i.e. policy that gives priority to the buying power (highest priority given to DT truck since it purchases the most); policy that gives priority to a certain group of customers who place an order in advance etc.
- Further explore additional policies on loader scheduling part i.e. policy that gives priority for the popular product stockpile, policy that force loader to stay in one zone area before moving to next zone etc.
- Further explore additional combined policies of the new proposed policies
- Take into the account of uncertainty of production pattern in production planning part of future change in demand
- Take into the account of seasonal effect by testing the model against other seasonal setting.
- Collect data during different time period of a year long to see whether there is a change in trend of the incoming trucks and truck arrival schedule
- Further explore the economic benefit in case of the investing in additional loader i.e. how many years does it take to pass the break-even of the cost, the increase in profit by having this extra loader serving additional customers. It is to be noted that by having additional loader in the system, it would lower both

average flow of truck as well as the utilization of loader. However, the question of investing in another loader depends on the result of economic benefit analysis.

- Take into the account of the limitation of buffer zone of the physical waiting area

Exhibit 1: Example of how to use Input Analyzer

To set an example of how Input Analyzer is used to identify the distribution, TRIA(3.52,4.19,5.88) distribution for DT truck’s loading time is selected to illustrate the process.

To run a simulation model of a current process, a distribution of data collected needs to be determined. In order to reflect the randomness of the data, a statistic programed built-in with Arena software, called Input Analyzer, is used. By using Input Analyzer, a probability distribution that fits each data set are identified. Table (i) summarizes type of distribution, function that is used in Arena to identify type of the distribution, as well as parameters that are used in the distribution.

Table (i): Arena distributions and their parameters

Distribution	**Arena name**	**Arena parameters**
Normal	NORM ()	Mean, StdDev
Triangular	TRIA ()	Min, Mode, Max
Uniform	UNIF()	Min, Max
Erland	ERLA()	ExpoMean, k
Beta	BETA ()	Beta, Alpha
Gamma	GAMM()	Beta, Alpha
Lognormal	LOGN()	LogMean, LogStdDev
Weibull	WEIB()	Beta, Alpha

By using the raw collecting data set with the function “Fit all” in Input Analyzer, it generates *Distribution Summary* as seen in Figure (i) for the example of DT’s loading time distribution. The first two lines of the *Distribution Summary* indicate a type of distribution, its function and parameters used. In this particular case, it can be concluded that the distribution for DT’s Loading time is TRIA(3.52,4.19,5.88). In addition, the *Distribution Summary* also shows the result for goodness of fit tests: Chi-Square Test and Kolmogorov-Smirnov Test (KS Test). Chi-Square Test is used when number of data points is more than 50 whereas KS Test is used when the number of data points is less than 50. Since there are 50 data points collected for DT's Loading time, the Chi Square Test shows that the distribution that was chosen for DT loading time has p-value of 0.559 which is statistically significant at an alpha level of 0.05.

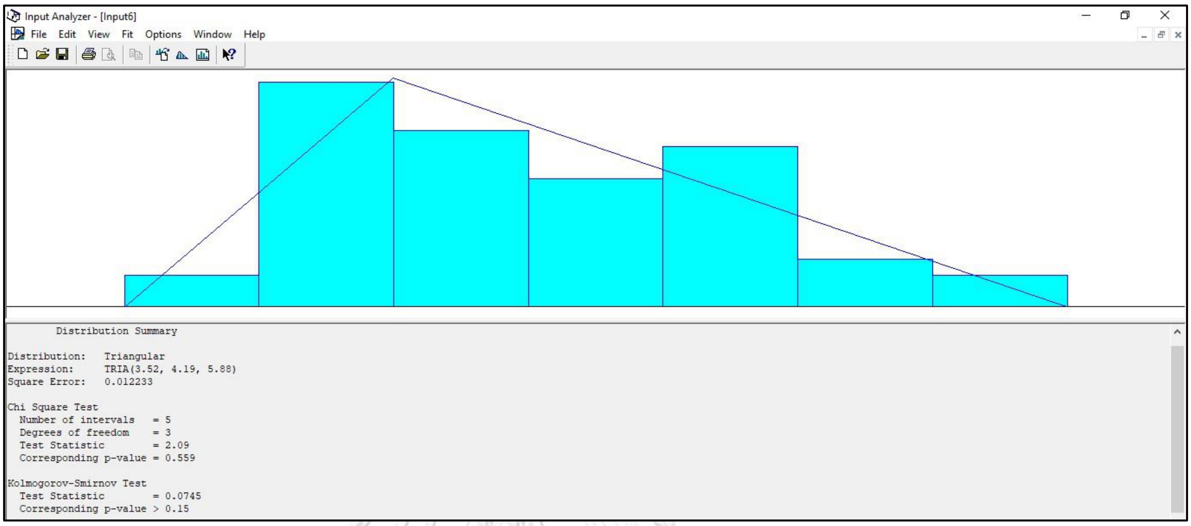

Figure (i): Input Analyzer's distribution summary of DT's loading time distribution

Exhibit 2: Two Sample T-Test result for simulation validation

Two-Sample T-Test and CI (Number of trucks out in each week: 6T)

```
Sample    N   Mean  StDev  SE Mean
1         7  344.9   73.8       28
2       101  365.6   10.2      1.0


Difference = mu (1) - mu (2)
Estimate for difference:  -20.7
95% CI for difference:  (-89.0, 47.6)
T-Test of difference = 0 (vs not =): T-Value = -0.74  P-Value = 0.486  DF =
6
```

Two-Sample T-Test and CI (Number of trucks out in each week: 10T)

```
Sample    N   Mean  StDev  SE Mean
1         7   81.3   26.0      9.8
2       101  96.91   5.11     0.51


Difference = mu (1) - mu (2)
Estimate for difference:  -15.62
95% CI for difference:  (-39.72, 8.48)
T-Test of difference = 0 (vs not =): T-Value = -1.59  P-Value = 0.164  DF =
6
```

Two-Sample T-Test and CI (Number of trucks out in each week: DT)

```
Sample    N    Mean  StDev  SE Mean
1         7   192.1   18.9      7.1
2       101  192.16   6.47     0.64


Difference = mu (1) - mu (2)
Estimate for difference:  -0.02
95% CI for difference:  (-17.52, 17.48)
T-Test of difference = 0 (vs not =): T-Value = -0.00  P-Value = 0.998  DF =
6
```

Two-Sample T-Test and CI (Total time spent for 6T)

```
Sample     N  Mean  StDev  SE Mean
1       1135  30.3   24.0     0.71
2        101  35.4   27.2      2.7


Difference = mu (1) - mu (2)
Estimate for difference:  -5.07
95% CI for difference:  (-10.62, 0.48)
T-Test of difference = 0 (vs not =): T-Value = -1.81  P-Value = 0.073  DF =
114
```

Two-Sample T-Test and CI (Total time spent for 10T)

```
Sample    N  Mean  StDev  SE Mean
```

```
1        269  35.7   34.8      2.1
2        101  37.3   25.7      2.6


Difference = mu (1) - mu (2)
Estimate for difference:  -1.60
95% CI for difference:  (-8.15, 4.95)
T-Test of difference = 0 (vs not =): T-Value = -0.48  P-Value = 0.631  DF =
242
```

Two-Sample T-Test and CI (Total time spent for DT)

```
Sample     N  Mean  StDev  SE Mean
1        550  45.0   39.2      1.7
2        101  47.4   33.8      3.4


Difference = mu (1) - mu (2)
Estimate for difference:  -2.35
95% CI for difference:  (-9.78, 5.08)
T-Test of difference = 0 (vs not =): T-Value = -0.63  P-Value = 0.533  DF =
153
```

Two-Sample T-Test and CI (Amount sold of product 1 in each week)

```
Sample     N    Mean  StDev  SE Mean
1          7    1533    700      264
2        101  1549.1   69.4      6.9


Difference = mu (1) - mu (2)
Estimate for difference:  -16
95% CI for difference:  (-663, 632)
T-Test of difference = 0 (vs not =): T-Value = -0.06  P-Value = 0.954  DF =
6
```

Two-Sample T-Test and CI (Amount sold of product 2 in each week)

```
Sample     N  Mean  StDev  SE Mean
1          7  2863    505      191
2        101  3040    125       12


Difference = mu (1) - mu (2)
Estimate for difference:  -177
95% CI for difference:  (-645, 291)
T-Test of difference = 0 (vs not =): T-Value = -0.93  P-Value = 0.390  DF =
6
```

Two-Sample T-Test and CI (Amount sold of product 3 in each week)

```
Sample     N   Mean  StDev  SE Mean
1          7    812    279      105
2        101  893.5   57.2      5.7


Difference = mu (1) - mu (2)
Estimate for difference:  -82
```

```
95% CI for difference:  (-340, 176)
T-Test of difference = 0 (vs not =): T-Value = -0.78  P-Value = 0.467  DF =
6
```

Two-Sample T-Test and CI (Amount sold of product 4 in each week)

```
Sample    N    Mean  StDev  SE Mean
1         7    2701   1024      387
2       101  2650.5   53.8      5.4


Difference = mu (1) - mu (2)
Estimate for difference:  50
95% CI for difference:  (-897, 997)
T-Test of difference = 0 (vs not =): T-Value = 0.13  P-Value = 0.901  DF = 6
```

Two-Sample T-Test and CI (Amount sold of product 5 in each week)

```
Sample    N   Mean  StDev  SE Mean
1         7    183    209       79
2       101  167.5   34.0      3.4


Difference = mu (1) - mu (2)
Estimate for difference:  15.3
95% CI for difference:  (-178.4, 209.0)
T-Test of difference = 0 (vs not =): T-Value = 0.19  P-Value = 0.853  DF = 6
```

Two-Sample T-Test and CI (Amount sold of product 6 in each week)

```
Sample    N   Mean  StDev  SE Mean
1         7    588    315      119
2       101  629.1   63.3      6.3


Difference = mu (1) - mu (2)
Estimate for difference:  -41
95% CI for difference:  (-332, 251)
T-Test of difference = 0 (vs not =): T-Value = -0.34  P-Value = 0.744  DF =
6
```

Two-Sample T-Test and CI (Amount sold of product 7 in each week)

```
Sample    N   Mean  StDev  SE Mean
1         7    495    481      182
2       101  832.2   81.1      8.1


Difference = mu (1) - mu (2)
Estimate for difference:  -337
95% CI for difference:  (-782, 108)
T-Test of difference = 0 (vs not =): T-Value = -1.85  P-Value = 0.114  DF =
6
```

Exhibit 3: Comparison of ending time of the Base model and SPT model

Table (ii) and Table (iii) shows the ending time of the last entity (truck) in the base model and SPT model, respectively. The time from Arena simulation was recorded b fore converted into the actual day, ending minutes, and in hour, minute, second format, as can be seen in the two tables. The study uses Minitab software to conduct a Two-Sample T-Test to see whether there is a significant difference of the ending time between the two systems. Below shows the comparison of the ending time of truck from base model (refers to Table (ii)) and SPT model (refers to Table (iii)). From the Two-Sample T-Test using Minitab software, it can be concluded that with 95% confidence there is no significant difference between the ending time of the two models.

Two-Sample T-Test and CI

```
                                  SE
Sample   N    Mean  StDev  Mean
1       24  1015.3   60.9    12
2       24  1021.2   66.1    13


Difference = mu (1) - mu (2)
Estimate for difference:  -5.9
95% CI for difference:  (-42.8, 31.1)
T-Test of difference = 0 (vs not =): T-Value = -0.32  P-Value = 0.750  DF =
45
```

Table (ii): Ending time of last entity (truck) in Base model

Base Model					
Time from Arena Simulation	Conversion of day and ending time				
	Day	Ending Minutes	Hour	Minute	Second
974.53	1	974.53	16	14.53	31.62
2569.61	2	1129.61	18	49.61	36.43
3864.21	3	984.21	16	24.21	12.60
5308.66	4	988.66	16	28.66	39.32
6791.20	5	1031.20	17	11.20	12.18
8214.97	6	1014.97	16	54.97	57.96
9637.39	7	997.39	16	37.39	23.67
11177.61	8	1097.61	18	17.61	36.77
12494.95	9	974.95	16	14.95	57.21
13930.11	10	970.11	16	10.11	6.31
15338.75	11	938.75	15	38.75	44.92
16784.07	12	944.07	15	44.07	4.14
18293.65	13	1013.65	16	53.65	38.74
19863.65	14	1143.65	19	3.65	38.86
21189.73	15	1029.73	17	9.73	43.63
22608.09	16	1008.09	16	48.09	5.35
24025.84	17	985.84	16	25.84	50.48
25499.47	18	1019.47	16	59.47	27.94
26929.30	19	1009.30	16	49.30	18.17
28522.80	20	1162.80	19	22.80	48.15
29824.07	21	1024.07	17	4.07	3.98
31190.06	22	950.06	15	50.06	3.84
32638.27	23	958.27	15	58.27	16.31
34136.61	24	1016.61	16	56.61	36.34

Base model : Average of ending minutes = 1015.32

Standard deviation of ending minutes = 60.92

Table (iii): Ending time of last entity (truck) in SPT model

SPT model					
Time from Arena Simulation	Conversion of day and ending time				
	Day	Ending Minutes	Hour	Minute	Second
1024.13	1	1024.13	17	4.13	8.03
2600.45	2	1160.45	19	20.45	26.86
3892.38	3	1012.38	16	52.38	22.64
5331.87	4	1011.87	16	51.87	52.50
6782.33	5	1022.33	17	2.33	19.72
8201.95	6	1001.95	16	41.95	57.26
9564.90	7	924.90	15	24.90	53.81
11238.17	8	1158.17	19	18.17	9.91
12484.21	9	964.21	16	4.21	12.39
13927.80	10	967.80	16	7.80	48.21
15377.27	11	977.27	16	17.27	16.46
16836.44	12	996.44	16	36.44	26.50
18278.93	13	998.93	16	38.93	55.54
19872.35	14	1152.35	19	12.35	21.15
21189.79	15	1029.79	17	9.79	47.12
22591.49	16	991.49	16	31.49	29.19
24058.63	17	1018.63	16	58.63	37.98
25499.97	18	1019.97	16	59.97	58.41
26872.49	19	952.49	15	52.49	29.33
28503.75	20	1143.75	19	3.75	44.81
29819.34	21	1019.34	16	59.34	20.27
31210.82	22	970.82	16	10.82	48.97
32701.13	23	1021.13	17	1.13	7.91
34088.26	24	968.26	16	8.26	15.48

SPT model : Average of ending minutes = 1021.20

Standard deviation of ending minutes = 66.06

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VITA

NAME	Chanayakan Chawaranggoon
DATE OF BIRTH	11 January 1992
PLACE OF BIRTH	Thailand
INSTITUTIONS ATTENDED	B.S. Industrial Engineering, Pennsylvania State Universtiy MBA, Sasin School of Management
HOME ADDRESS	450 Government Center Rd, Rimkok, Mueang, Chiang Rai Thailand