DEVELOPMENT OF SIMULATION MODELS FOR THE CEMENT LOADING PROCESS AT A CEMENT PLANT

A THESIS SUBMITTED TO THE GRADUATE DIVISION OF THE UNIVERSITY OF HAWAI‘I AT MĀNOA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

IN

CIVIL ENGINEERING

DECEMBER 2013

By

Punyaanek Srisurin

Thesis Committee:

Amarjit Singh, Chairperson
Lin Shen
Peter Flachsbart
ACKNOWLEDGEMENT

I wish to express my appreciation and gratitude to my advisor Professor Amarjit Singh, for his excellent guidance and encouragement throughout this research. The thesis would never be done without his influential guidance and useful suggestions, which greatly influenced the direction of the work.

I would also like to thank my Thesis Committee, Professor Peter Flachsbart and Professor Lin Shen, for their helpful suggestions and valuable comments, which led to substantial improvements on my work. Further, my great appreciation goes to the Asia Cement Plant for approving their bulk cement loading process as a case study for my thesis. Besides, I would like to thank the plant administrative supervisor, Mr. Apirak Sawasdiwong, and all the staff for their supervision and facilitation during my two months working at the plant.

Finally, I would like to extend my thanks to my grandmother, Nalinee Srisurin, and my younger sister, Piyapon Srisurin, for their supports and encouragements through my hard times. Last but not least, I would like to thank my parents Wasunt Srisurin and Jarunee Srisurin. Without their love and supports, my education here would never happen.

The thesis is dedicated to my beloved grandfather, Suthep Srisurin, who had been waiting patiently for this day to come until the last minute of his life.

Punyaanek Srisurin

University of Hawaii at Manoa
October 2013
Development of Simulation Models for the Cement Loading Process at a Cement Plant

ABSTRACT

In queuing systems, waiting time and idle time are considered non-productive since waiting time limits opportunities to improve productivity, while idle time creates wasteful operation costs. Bulk cement loading process is a good example to illustrate the problem in logistics distribution system. Reduction of waiting time and throughput time of cement trucks in cement loading process requires such additional resources as loading machines and operators, which trade off additional operation costs for cement distributors; however, an abundant number of input resources could create idle time. On the other hand, minimizing the input resources can significantly save costs for entrepreneurs; however, waiting time and throughput time of trucks could be excessive that limits the number of trips that trucks could travel to transport cement. To maximize utilities of cement trucks and input resources, a trade-off between truck waiting time and server idle time needs to be resolved.

The current practice yields average waiting time of 26.0 minutes per truck and throughput time of 71.5 minutes per truck. According to the survey conducted by the plant, the current practice reflects the declining in customer satisfaction since the throughput time is high. To say, the current practice causes, on average, 47.5 minutes of non-productive time per truck, compared to 24.0 minutes of cement loading time. Consequently, simulations need to be performed for the sake of determining some balance between truck waiting time and idle time of servers.
The primary objective of this study is to develop a simulation model that maximizes the utilization factor of truck waiting time and machine idle time in cement loading process. In addition, among the models showing maximum utilization factor, the study aims to pick up the potential model that can reduce truck waiting time and queue length, with as lowest machine idle time as possible. By using EZStrobe software, the current approach of the cement loading process was simulated based on the data obtained between August 2012 and June 2013. Model validation was performed by comparing results from the process simulation model with the results obtained from statistics to indicate accuracy of the simulation approach before proceeding to making improvements on the model. Various simulation models were developed by adjusting the process and allocating resources to predict total costs, average idle time of loading machines, average waiting time, average queue length, and average throughput time of trucks for each model. Sensitivity analysis were performed to determine the best practice that yields the greatest utilization factor and improve the overall performance of the process by minimizing truck waiting time, queue length, and machine idle time, with reasonable corresponding cost.

The research was conducted based on a case study of the cement loading system at Asia Cement Plant by using population data collected during August 2012 - June 2013. The current model and improved simulation models, alongside with their results, were graphically and numerically presented to illustrate potential of the models in terms of maximizing the utilization factor. In addition, in-depth analyses were performed on the raw data to determine appropriate statistical distributions and characteristics for all parameters used in the simulation models.
# TABLE OF CONTENTS

ACKNOWLEDGEMENT ........................................................................................................... ii

ABSTRACT .............................................................................................................................. iii

LIST OF TABLES ..................................................................................................................... vii

LIST OF FIGURES .................................................................................................................. viii

CHAPTER 1 INTRODUCTION ................................................................................................. 1
  1.1 Technical Background ................................................................................................. 2
  1.2 Objectives and Scope of the Study ............................................................................. 4
  1.3 Literature Review ....................................................................................................... 5

CHAPTER 2 EZSTROBE MODELING SOFTWARE AND RELATED THEORIES .................. 12
  2.1 EZStrobe ..................................................................................................................... 12
  2.1.1 EZStrobe Modeling Elements ................................................................................. 13
  2.1.2 Coding in EZStrobe .............................................................................................. 17
  2.2 Key Components of the Queuing Systems ................................................................. 20

CHAPTER 3 STATISTICAL ANALYSIS ON PARAMETERS .............................................. 21
  3.1 Cement Loading Process Overview ........................................................................... 21
  3.2 Statistical Analysis on Parameters ........................................................................... 22
  3.2.1 Interarrival Time Characteristics and Distribution Analysis ................................... 23
  3.2.2 Cement Loading Time Analysis .............................................................................. 42
  3.2.3 Processing Times Analysis ..................................................................................... 52

CHAPTER 4 CEMENT LOADING PROCESS MODELING ............................................. 61
  4.1 Truck Arrival Characteristics Simulation .................................................................. 61
  4.2 Process Simulation ..................................................................................................... 64
  4.3 Queuing and Cement Loading Characteristics Simulations ..................................... 66
4.3.1 Simulation Model of Queue Line 1 ............................................. 70
4.3.2 Simulation Model of Queue Line 2 ............................................. 72
4.4 Simulation Results and Model Validation ................................. 74
4.4.1 Operation and Labor Costs ..................................................... 74
4.4.2 Program Coding ................................................................. 78
4.4.3 Simulation Results ............................................................... 85
4.4.4 Model Validation ............................................................... 90

CHAPTER 5 IMPROVEMENT MODELS FOR THE CEMENT
LOADING PROCESS WITH RESULTS AND SENSITIVITY
ANALYSES ............................................................... 92
5.1 Model Improvement .............................................................. 92
5.1.1 Cement Loading Process Model of the Merged-Queue System ...... 93
5.2 Results and Sensitivity Analysis of the Merged-Queue Cement
Loading Process Models with Adjustments on the Number of Cement
Loading Channels ............................................................... 102
5.3 Results and Sensitivity Analysis of the Merged-Queue Cement
Loading Process Models with One Additional Loading Channel
during Peak and PM Mid-Peak Periods .................................... 104
5.4 Results and Sensitivity Analysis of the Merged-Queue Cement
Loading Process Models with Two Additional Loading Channels
during Peak and PM Mid-Peak Periods .................................... 115
5.5 Results and Sensitivity Analysis of the Merged-Queue Cement
Loading Process Models with Three Additional Loading Channels
during Peak and PM Mid-Peak Periods .................................... 126

CHAPTER 6 DISCUSSION AND CONCLUSIONS ......................... 132
Bibliography .............................................................................. 138
Appendix .................................................................................... 141
LIST OF TABLES

Table 2-1 Global variables used in EZStrobe software (Martinez, 2001) .......... 18
Table 3-1 Average truck arrival rate of each hour during the day ................. 25
Table 3-2 Average truck arrival rates and total arrival classified by day .......... 28
Table 3-3 Average truck arrival rate, interarrival time, and total arrival during each phase ................................................................................. 32
Table 3-4 Average truck arrival rate, interarrival time, and total arrival during each phase ................................................................................. 42
Table 4-1 Prediction of the durations from the simulation model of the default system ................................................................................. 86
Table 4-2 Prediction of costs from the simulation model of the default system .. 86
Table 4-3 Indicators results of the simulation model of the default system ....... 86
Table 4-4 Validation of the simulation model of the default system ............... 91
Table 5-1 Prediction of the durations from the simulation model after merging queues ................................................................................. 98
Table 5-2 Prediction of costs from the simulation model after merging queues ... 98
Table 5-3 Indicators results of the simulation model after merging queues ....... 99
Table 5-4 Sensitivity analysis on the cement loading process models with various set of cement loading channels ................................. 102
Table 5-5 Sensitivity analysis on the cement loading process models with one additional loading channel during peak and PM mid-peak periods.... 105
Table 5-6 Sensitivity analysis on the cement loading process models with two additional loading channels during peak and PM mid-peak periods .. 116
Table 5-7 Sensitivity analysis on the cement loading process models with three additional loading channels during peak and PM mid-peak periods .. 127
Table 6-1 Comparison of results among the interest models ....................... 132
LIST OF FIGURES

Figure 2-1 An example of a Queue node .................................................. 13
Figure 2-2 An example of a Combi node .................................................. 14
Figure 2-3 An example of a Normal node .................................................. 15
Figure 2-4 An example of a Draw Link ...................................................... 15
Figure 2-5 An example of a Release Link ................................................... 16
Figure 2-6 An example of a Fork Node ...................................................... 16
Figure 2-7 An example of a Branch Link .................................................... 17
Figure 2-8 An example of a result bar and its shape data box ................. 19
Figure 2-9 An example of a parameter bar and its shape data box .......... 19
Figure 2-10 A result bar of a result involving with several variables ....... 19
Figure 2-11 Basic components of a queuing system ................................. 20
Figure 3-1 Statistical distribution of truck interarrival time in cement loading
    process ................................................................. 23
Figure 3-2 Statistical distribution of truck interarrival time from ARENA Input
    Analyzer ............................................................. 24
Figure 3-3 Average hourly truck arrival rates categorized by day .......... 26
Figure 3-4 Comparison between arrival characteristics on Weekdays and
    Weekends ........................................................... 27
Figure 3-5 Average daily truck arrival rates categorized by day ............ 29
Figure 3-6 Arrival characteristics of trucks at the cement plant during 24-hour
    period ................................................................. 30
Figure 3-7 Interarrival time distribution result of the off-peak period from
    ARENA Input Analyzer ............................................ 33
Figure 3-8 Statistical distribution of truck interarrival time during off-peak period ................................................................. 33
Figure 3-9 Distribution of total truck arrival during the off-peak period from ARENA Input Analyzer ........................................ 34
Figure 3-10 Interarrival time distribution result of the AM mid-peak period from ARENA Input Analyzer ........................................ 35
Figure 3-11 Statistical distribution of truck interarrival time during AM mid-peak period ................................................................. 36
Figure 3-12 Distribution of total truck arrival during the AM mid-peak period from ARENA Input Analyzer ........................................ 36
Figure 3-13 Interarrival time distribution result of the peak period from ARENA Input Analyzer ................................................................. 38
Figure 3-14 Statistical distribution of truck interarrival time during the peak period ................................................................. 38
Figure 3-15 Distribution of total truck arrival during the peak period from ARENA Input Analyzer ................................................................. 39
Figure 3-16 Interarrival time distribution result of the PM mid-peak period from ARENA Input Analyzer ................................................................. 40
Figure 3-17 Statistical distribution of truck interarrival time during the PM mid-peak period ................................................................. 41
Figure 3-18 Distribution of total truck arrival during the PM mid-peak period from ARENA Input Analyzer ................................................................. 41
Figure 3-19 Loading time distribution result of channel 23 from ARENA Input Analyzer ................................................................. 43
Figure 3-20 Loading time distribution result of channel 24 from ARENA Input Analyzer ................................................................. 44
Figure 3-21 Loading time distribution result of channel 25 from ARENA Input Analyzer ................................................................. 45
Figure 3-22 Loading time distribution result of channel 26 from ARENA Input Analyzer ................................................................. 46
Figure 3-23 Loading time distribution result of channel 27 from ARENA Input Analyzer ................................................................. 47
Figure 3-24 Loading time distribution result of channel 28 from ARENA Input Analyzer ................................................................. 48
Figure 3-25 Loading time distribution result of channel 30 from ARENA Input Analyzer ................................................................. 49
Figure 3-26 Loading time distribution result of channel 31 from ARENA Input Analyzer ................................................................. 50
Figure 3-27 Loading time distribution result of channel 32 from ARENA Input Analyzer ................................................................. 51
Figure 3-28 Registration time distribution result from ARENA Input Analyzer .. 53
Figure 3-29 Truck proceeding time distribution result from ARENA Input Analyzer ................................................................. 54
Figure 3-30 Inlet weight measuring time distribution result from ARENA Input Analyzer ................................................................. 55
Figure 3-31 Distribution result of travel time to queue from ARENA Input Analyzer ................................................................. 56
Figure 3-32 Sealing time distribution result from ARENA Input Analyzer …… 57
Figure 3-33 Distribution result of travel time to weighbridge from ARENA Input Analyzer ................................................................. 59
Figure 3-34 Distribution result of outlet weight checking time from ARENA Input Analyzer ................................................................. 60
Figure 4-1 Truck arrival characteristics simulation model from EZStrobe ........ 63
Figure 4-2 Process simulation model from EZStrobe .......................... 65
Figure 4-3 Queuing characteristics model from EZStrobe .................. 67
Figure 4-4 Cement loading system of queue line 1 from EZStrobe .......... 68
Figure 4-5 Cement loading system of queue line 2 from EZStrobe ............ 69
Figure 4-6 Parameters used to calculate the results of the model ............. 77
Figure 4-7 Program codes to obtain time results of the model ................ 82
Figure 4-8 Program codes to determine utilization results of the model ........ 84
Figure 4-9 Graph shows amount of trucks in the system over time for default
  model ........................................................................................................ 87
Figure 4-10 Graph shows the cumulative number of trucks complete the
  process over time .................................................................................. 88
Figure 4-11 Graph shows the amount of trucks in the system during 24-hour
  period ..................................................................................................... 88
Figure 4-12 Chart shows the number of trucks in queue line 1 over time .... 89
Figure 4-13 Chart shows the number of trucks in queue line 2 over time ..... 90
Figure 5-1 Cement loading system of the merged queue model from EZStrobe .. 94
Figure 5-2 Cement loading system of the merged queue model from EZStrobe
  (continued) .......................................................................................... 95
Figure 5-3 Cement loading system of the merged queue model from EZStrobe
  (continued) .......................................................................................... 96
Figure 5-4 Graph shows amount of trucks in the system over time after
  merging queues .................................................................................... 99
Figure 5-5 Graph shows the cumulative number of trucks complete the process
  over time ............................................................................................... 100
Figure 5-6 Graph shows the amount of trucks in the system during 24-hour
  period ................................................................................................. 101
Figure 5-7 Chart shows the number of trucks in the loading queue over time ... 101
Figure 5-8 Trends of utilization factor when the number loading machines changes ................................................................. 104

Figure 5-9 Trends of utilization factor when the number loading machines changes under the condition that one additional server is provided during the peak duration ................................................................. 107

Figure 5-10 Cement loading system of the merged queue model of 3 loading channels with one extra channel during peak and PM mid-peak periods .................................................................................... 109

Figure 5-11 Cement loading system of the merged queue model of 3 loading channels with one extra channel during peak and PM mid-peak periods (continued) ................................................................. 110

Figure 5-12 Cement loading system of the merged queue model of 3 loading channels with one extra channel during peak and PM mid-peak periods (continued) ................................................................. 111

Figure 5-13 Cement loading system of the merged queue model of 4 loading channels with one extra channel during peak and PM mid-peak periods .................................................................................... 112

Figure 5-14 Cement loading system of the merged queue model of 4 loading channels with one extra channel during peak and PM mid-peak periods (continued) ................................................................. 113

Figure 5-15 Cement loading system of the merged queue model of 4 loading channels with one extra channel during peak and PM mid-peak periods (continued) ................................................................. 114

Figure 5-16 Trends of utilization factor when the number loading machines changes under the condition that two additional servers are provided during the peak duration ......................................... 118
Figure 5-17 Cement loading system of the merged queue model of 3 loading channels with 2 extra channels during peak and PM mid-peak periods .......................................................... 120

Figure 5-18 Cement loading system of the merged queue model of 3 loading channels with 2 extra channels during peak and PM mid-peak periods (continued) .......................................................... 121

Figure 5-19 Cement loading system of the merged queue model of 3 loading channels with 2 extra channels during peak and PM mid-peak periods (continued) .......................................................... 122

Figure 5-20 Cement loading system of the merged queue model of 4 loading channels with 2 extra channels during peak and PM mid-peak periods .......................................................... 123

Figure 5-21 Cement loading system of the merged queue model of 4 loading channels with 2 extra channels during peak and PM mid-peak periods (continued) .......................................................... 124

Figure 5-22 Cement loading system of the merged queue model of 4 loading channels with 2 extra channels during peak and PM mid-peak periods (continued) .......................................................... 125

Figure 5-23 Cement loading system of the merged queue model of 3 loading channels with 3 extra channels during peak and PM mid-peak periods .......................................................... 129

Figure 5-24 Cement loading system of the merged queue model of 3 loading channels with 3 extra channels during peak and PM mid-peak periods (continued) .......................................................... 130

Figure 5-25 Cement loading system of the merged queue model of 3 loading channels with 3 extra channels during peak and PM mid-peak periods (continued) .......................................................... 131
Figure 6-1 Chart shows the number of trucks in the loading queue over time for the model using 3 servers with an additional server during peak and PM mid peak periods ................................................. 134

Figure 6-2 Chart shows the number of trucks in the loading queue over time for the model using 3 servers with 2 additional servers during peak and PM mid peak periods ................................................. 135

Figure 6-3 Chart shows the number of trucks in the loading queue over time for the model using 3 servers with 3 additional servers during peak and PM mid peak periods ................................................. 135

Figure 6-4 Chart shows the number of trucks in the loading queue over time for the model using 4 servers with an additional server during peak and PM mid peak periods ................................................. 136

Figure 6-5 Chart shows the number of trucks in the loading queue over time for the model using 4 servers with 2 additional servers during peak and PM mid peak periods ................................................. 136

Figure A-1 Cement loading sector of the Asia Cement Plant .................. 141
Figure A-2 A bulk cement truck waiting in the loading queue ............... 142
Figure A-3 The control diagram of the cement loading process at line 2 ...... 142
Figure A-4 The control diagram of the cement loading process at line 1..... 143
Figure A-5 The weighbridge station ..................................................... 143
Figure A-6 The loading queue at the line 1.......................................... 144
Figure A-7 Trucks were loading with bulk cement at the loading channels ..... 144
Figure A-8 Trucks are loading with bulk cement at the loading channels ..... 145
Figure A-9 A cement loading channel with a weighbridge at the base (left),

        A bulk cement loading machine (right) ............................... 145
Figure A-10 The cement loading machine is attached to the cement truck ..... 146
Chapter 1

INTRODUCTION

Time is a primary factor that contributes to productivity and utilization measurements for not only manufacturing and construction processes but also freight transportation and logistics systems. Waiting time is considered non-productive since it decreases opportunities for trucks to run more trips and carry more cement, while idle time wastes operation costs for servers. Bulk cement loading process, which is an initial process in material provision for construction and concrete industries, is a good example to illustrate the problem in logistics distribution system. In general, reduction of waiting time and throughput time of cement trucks in cement loading process requires additional input resources, such as the number of servers and operators, which increase operation costs for cement distributors. However, an abundant number of input resources could provide additional idle time. On the other hand, minimizing the input resources can significantly save costs for entrepreneurs; however, waiting time and throughput time of trucks could be excessive that reduces the number of trips that trucks could travel to transport cement. In other words, minimizing machine idle time by reducing input resources could unintentionally increase non-productive time of trucks, while maximizing capacity of the system by adding input resources could excessively increase idle time of the machines and operators. Consequently, the appropriate number of servers needs to be determined and some parts of the process need to be improved.
1.1 Technical Background

The current practice yields average waiting time of 26.0 minutes per truck and throughput time of 71.5 minutes per truck. According to the survey conducted by the plant, the current practice reflects the declining in customer satisfaction since the throughput time is three times greater than average cement loading time, which is 24.0 minutes. In other words, the current practice causes, on average, 47.5 minutes of non-productive time per truck. Consequently, an optimization needs to be performed for the sake of determining some balance between truck waiting time and machine idle time.

Idle time has been used to measure non-productive time of machines, laborers, and other input resources, mostly in manufacturing systems and construction processes. Generally, idle time occurs due to the capacity of a system outnumbers the input flow of entities. The main reason to minimize idle time is that to decrease excessive operation costs and maximize the utility of input resources. However, the existence of idle time may sometimes be considered as a safety factor to handle peak time when arrival rate is extremely high, as a result of uncertainty.

Waiting time has been widely used as an indicator to measure efficiency of queuing systems. The occurrence of waiting time is predominantly due to queue, caused by bottlenecks or delay tasks in a process, when the inlet flow rate of entity outnumbers the capacity of the system to serve the inlet flow. Normally, waiting time reduction at queue directly leads to the declining of throughput time of the process, given that the other tasks of the process remain unchanged over time. In this case study, the bottleneck is found to be at the cement loading stations, causing
two queue lines with average waiting time of 26.0 minutes per truck. In addition, the waiting time makes up 36.4% of the throughput time.

Two interesting features of queuing in the cement loading system have been observed:

1) For a single queue, if a delay of w minutes occurs to a truck loading cement at the station, additional w minutes of waiting time will be applied to every truck waiting in the line at that time.
2) Given that there are N trucks queuing in a single queue and a loaded truck has just departed from the station, a newly arrived truck is expected to spend NS minutes waiting in the line, when S is average cement loading time.

Generally, waiting time declines in three ways: when the arrival rate of entity declines, when the capacity of the servers increases, and the combination of these two events. In other words, in order to reduce waiting time, queue length needs to be shortened. However, reducing waiting time by limiting the arrival rate is unlikely to be performed in this study since cement loading process is a commercial activity, which the maximization of arrival rate benefits sales; therefore, reducing truck waiting time by increasing capacity of cement loading servers is opted to be performed in simulation models. At this point, the question is that how large the capacity should be, when the additional capacity could generate excessive idle time for machines and laborers. Consequently, an optimization needs to be conducted to find the best model on the basis of improving the system flow by minimizing truck waiting time with the least amount of machine idle time consumed.
Another essential terminology in this study is throughput time, which is defined as the total time that a truck spends dwelling in the cement loading system. The throughput time is started to count when a truck arrives at the front office to receive an RFID tag, and stopped when the truck departs from the last station of the system, the outlet weighbridge.

1.2 Objectives and Scope of the Study

The primary objective of this study is to develop a simulation model that maximizes the utilization factor of truck waiting time and machine idle time in cement loading process. In addition, among the prepared models showing maximum utilization factor, the study aims to pick up the potential model that can reduce truck waiting time and queue length with as lowest machine idle time as possible. In other words, on the basis of the same level of utilization, the model that yields the lowest input of resources would be preferred. The current approach of the cement loading process will be simulated based on the data obtained between August 2012 and June 2013 via EZStrobe simulation software. Results from the process simulation model will be compared with the results obtained from statistics to indicate accuracy of the simulation before developing improvement model. Various simulation models will be developed by adjusting the process and allocating resources to predict total costs, average idle time of loading machines, average waiting time, average queue length, and average throughput time of trucks for each model. Sensitivity analysis will be performed to determine the best practice that yields the greatest utilization factor and improve the overall performance of the process by minimizing truck waiting time, queue length, and machine idle time, with reasonable related cost.
The research was conducted based on a case study of the cement loading system at Asia Cement Plant by using population data collected during August 2012 - June 2013. Although there are three types of cement produced at the plant: ordinary Portland cement type 1, mixed cement, and masonry cement, the bulk cement loading process, which is the loading process of Portland cement type 1, is limited by the scope of this study. Therefore, the study focuses merely on the bulk cement loading process at the cement production plant by seeing the cement truck as the main entity, while the cement loading servers are seen as resource. The scope of the study covers all the activities occur within the cement loading sector of the plant, starting when a truck arrives at the registration office and ending when the truck departs from the outlet weighbridge.

Since the project is done for making improvement on the cement loading system at the Asia Cement Plant, the study opts to focus on the operation costs subjected to changes in the number of laborers and costs from electricity consumption, reflected by the operation time of cement loading machines, without touching opportunity cost, fuel consumption cost, and tailpipe emission cost for cement trucks. Beside, such fixed costs as capital cost, land cost, and equipment cost are not considered in this study since the only changes in variable costs corresponding to the improvements need to be known.

1.3 Literature Review

There have been relatively little works in this area for development of simulation models for the cement loading process at the distribution sector of cement plants. In addition, the modeling and simulation works via EZStrobe are
mainly from a limited group of expertise in civil engineering field. Therefore, in this section, a review wide range simulation modeling works in various fields of engineering are provided as applied to the modeling and simulation of bulk cement loading process.

The process of designing and testing a Mathematical-logical model of a real system using a computer is the basis of simulation (Manuj, Mentzer, and Bowers, 2009). An attractive feature of the simulation is that it represents a real-world situation and provides a framework within which a given system can be observed, investigated, analyzed, and improved by adjusting parameters without the requirement to physically adopt the model to the real system, in which uncertainty and risk are inevitably taken (Zayed and Halpin, 2001). However, when developing a model, validation and verification are extremely important since some prior experience may be required for simulation model developers (Ioannou and Martinez, 1996).

Complex interaction among units is found to be a feature of not only the construction job site, but also general real-world queuing systems, in which the complexity of such parameters as interarrival time, operation time, and waiting time are not predictable. Therefore, dynamic system modeling is preferred over the classical mathematical modeling, e.g. queuing theory, when modeling a process with high complexity (Zayed and Halpin, 2001). To illustrate, the interarrival time distribution may not always be exponential as assumed in queuing theory; therefore, the result prediction should be more accurate when simulation tool is applied to the same problem since the interarrival time distribution can be examined and closely estimated to emulate the real arrival behavior. Furthermore, the normal distribution assumption for the service time of servers in queuing theory is occasionally true since, in most case, the distribution may be more fitted to other type of statistical distribution, such as gamma, beta, and Erlang.
EZStrobe is a general-purpose discrete-event simulation software primarily for modeling construction operations; however, the program is also applicable for modeling a wide variety of systems in any discipline, including complex operations. The operation of EZStrobe is annexed to STROBOSCOPE, a simulation programming language and system for modeling complex processes in a variety of areas ranging from construction to manufacturing, for the purpose of processing the results. In other words, he program simplifies the very advance modeling task (STROBOSCOPE), presenting the Activity Scanning interface by processing results at the Three-Phase Activity Scanning level (Martinez, 2001).

Zayed and Halpin (2001) conducted a simulation on concrete batch plant production to predict the systems production and finding a practice that optimize resource allocation by minimizing costs and truck operating durations for the concrete batch plant. The researchers adopted MicroCYCLONE as a simulation medium for developing models. The authors conducted sensitivity analysis on the results and used their own-invented decision index to measure the performance of each model. The best solution was determined and suggested to the plant based on the decision index. The conclusion was implied that the use of MicroCYCLONE to simulate the concrete batch plant production, at that time, is one of the most flexible and effective practice for predicting the cost and time related to the operation.

Another similar work was performed by Shehu and Jethro (2012) by studying a truck queue of the cement loading system at a manufacturing plant in Nigeria in order to minimize truck waiting time, which was found to be up to 3 days per truck. The study found that such a long waiting time occurs due to the unbalance between truck arrival and the capacity of the cement loading system. As a result, the authors studied the truck arrival rate, redesigned the system, and suggested the appropriate loading capacity for the system by adding more servers.
to reduce truck waiting time and shortened queue length. However, despite the truck arrival rate shown was not uniformly distributed, the researchers opted to handle the problem linearly and suggest an average loading capacity, by neglecting the fluctuation in truck arrival rate.

Several studies have been conducted to explore the methodologies to improve efficiency of cement production plants and cement loading process by suggest possible procedures. Alghadafi and Latif (2010) studied the operations in a cement plant by using a discrete-event simulation program to create a simulation model of a cement production plant that support supply chain management in cement industry by increasing productivity and reducing cost. The idea of the study is to illustrate the cement production process through simulation by creating a working map of each production phase, from quarry to dispatching, in order to be available for the plants to investigate, monitor, and improve their process. Rice (2003) suggested a solution to improve efficiency of the system and customer service. The objective of the study is to cope with the excessive truck waiting time and loading time problems, limited truck access, and safety hazards by redesigning the site plan to improve access for trucks and adopting an automated cement loading technology to reduce loading time. The results show that the automated cement loading machines significantly reduced loading time; thus, truck waiting time was also decreased. Similarly, Miller and Rogers (2007) also suggested the installation of automatic equipment to allow all shipping and receiving transactions to be initiated, monitored and completed by the driver via the use of an Automated Plant Portal System in order to reduce truck waiting time and loading time. In addition, Elhasia et al. (2013) propose a sustainable cement supply chain model using ARENA simulation software to implement the three-target scenarios: grind-to-order, pack-to-order, and make-to-stock plans. The researchers concluded that the cement production plants should implement the grind-to-order plan as their
production strategy in order to improve their economic, ecological, and social performance.

An interesting work was done by Vik et al. (2010) by adopting a discrete-event simulation tool called SIMIO to redesign the internal logistics system and monitoring weighting system of a cement plant. Various scenarios were created and tested for validation on system changes and their impacts on the overall system. The authors recommended the use of this simulation software to virtually implement a logistics control system to an existing or new cement plants to monitoring and modifying their systems without physical interventions.

Ioannou (1999) developed a simulation model for a project involving the haulage and placement of rip-rap for the construction of a dam to demonstrate how traffic-related queues are created at locations. The model, which was developed via STROBOSCOPE, also investigates the formation of moving queues of equipment that cannot pass each and travel together like a procession or a convoy. In addition, the animation was adopted to illustrate validation of the model.

Hassan (2007) studied and optimized the concrete paving operations of the reconstruction project on Interstate highway 74 in East Peoria, Illinois by using discrete event simulation software. Prior to developing improvement models, probabilistic density functions for the activities duration were determined and model validation was performed, alongside with the sensitivity analysis, which was conducted in the decision-making process to determine the best practice. Total operation time, productivity, costs of the operation, average truck delay, and idle times for the paver and the spreader were analyzed and found that 10 trucks, one paver, and one spreader were recommended by the author.

Beaudoin et al (2013) developed simulation models on log yard operations via discrete event simulation tool by focusing on the impact of different loader-to-truck strategies on truck cycle time and driving distance of loaders to improve the
truck cycle time and driving distance of loader. The results from the best solution show that the average truck cycle time reduced by 14.6% and the average distance traveled by the loaders decreased by 18.4%, when the loader serves all the trucks in the queue before moving to another queue containing a truck with the longest waiting time, which was proved to be more efficient than the first-in-first-out strategy.

Similarly, Cetin (2004) studied open pit truck-shovel haulage systems by developing a stochastic truck dispatching and production simulation model for a medium size open pit mine consisting of several production faces via computer simulation tool. However, the researcher opted to assume that all the parameters related to the truck cycle are normally distributed without testing, which may reflect the accuracy of the results from the model if such parameters are more fitted to other types of distributions.

Akbaş (2003) studied an approach for modeling and simulation of construction processes based on geometric models and techniques with considering spatial aspects of construction operations since the operations always involve with vertical-direction activities. He claimed that existing discrete event simulation techniques, at that time, do not use the spatial aspects in model definition and evaluation of results. The improved modeling and simulation techniques were provided for construction operations, in addition to the more effective use of geometry for construction practice.

An interesting research on waiting time reduction of a logistics network was conducted by Xiang (2009) by developing a simulation model of a public logistics network, which can be viewed as a priority queuing network with bulk arrivals and bulk service, in United States via Microsoft .NET framework to obtain minimal package average waiting time for the entire network.
Khoury, Kamat, and Ioannou (2007) demonstrated the application of simulation modeling and visualization in supporting airside airport operations. The research adopted the Detroit Metropolitan Wayne County Airport to be modeled via STROBOSCOPE and 3D animation program called VITASCOPE in order to evaluate the capability and accuracy of these programs on modeling the construction operations at the airport. The authors concluded that although the tools were originally designed for specific domains, it was effective on applying with operations involving the interaction of entities in multiple domains, such as airport.

An example of research dedicating to time-cost tradeoff analysis was conducted by Feng et al. (2000) to illustrate a tradeoff between time and cost in construction through a hybrid approach, which combines simulation techniques and genetic algorithms to solve such a problem under uncertainty. The authors claimed that simulation techniques are suitable for analyzing stochastic problems, while an additional general strategy is needed to guide for obtaining optimal solutions (Feng et al., 2000).

Gawda et al. (1998) conducted a research on the paving cycle of a highway resurfacing project, using MicroCyclone simulation software, to improve the productivity of construction operations by measuring different parameters and transforming to a utility factor that indicates the performance of the whole system. The utility factor shows that the optimal solution requires 12 trucks to perform for the highway resurfacing project, with 7% of unavoidable waste.
Chapter 2
EZSTROBE MODELING SOFTWARE AND RELATED THEORIES

2.1 EZStrobe

Most of the simulation software, especially in construction field, use some form of network based on Activity Cycle Diagrams to represent the essentials of a model, alongside with the use of clock advance and event generation mechanisms based on Activity Scanning or Three-Phase Activity Scanning. EZStrobe is a graphical simulation system based on extended and annotated Activity Cycle Diagrams that uses Three-Phase Activity Scanning (Martinez, 2001). To say, it simplifies the very advance modeling task, presenting the Activity Scanning interface by processing results at the Three-Phase Activity Scanning level.

Invented by Julio C. Martinez (1964 – 2013), EZStrobe is a general-purpose discrete-event simulation software primarily for modeling construction operations; however, the program is also applicable for modeling a wide variety of systems in any discipline, including complex operations. The operation of EZStrobe is annexed to STROBOSCOPE, a simulation programming language and system for modeling complex processes in a variety of areas ranging from construction to manufacturing, for the purpose of processing the results (Martinez, 2001). Therefore, EZStrobe uses only generic resources, but it is capable of modeling very complex operations without using characterized or compound resources (Ioannou, 2013).
2.1.1 EZStrobe Modeling Elements

All activity conditions and results in EZStrobe models are analyzed and presented in terms of resource amounts. When there are more than one unit of resource dwelling in the same location (e.g., in the same node), they are assumed to be indistinguishable, interchangeable, and exist in bulk quantities (Martinez, 2001). Although programming through functions and formula are require when obtaining the results in modeling, EZStrobe is predominantly a model-based simulation tool, in which graphical modeling elements are employed as essential components when constructing a simulation model. The essential modeling elements and their functions are explained below.

1) Queue Node

A Queue node is a modeling element that possesses idle resources. The name of the Queue, which can be set by the users, is shown at the center, as seen in Figure 2-1. At the beginning of a simulation Queues hold a certain number of resources, which is shown below the Queue name. Resources are placed in Queues when they are released by terminating instances of preceding Activities. They are removed from Queues by starting instances of succeeding Conditional Activities (Combi nodes). A Queue can only be followed by a Conditional Activity (Combi node) and it can follow any other node except another Queue (Martinez, 2001).

![Queue Node Diagram](image-url)

Figure 2-1 An example of a Queue node
2) **Conditional Activity (Combi Node)**

A Conditional Activity (Combi), as seen in Figure 2-2, is a modeling element that represents tasks that can start whenever the resources that are available in the Queues that precede it are sufficient to support the task. The name of the Conditional Activity, which can be edited by users, is shown at the center. The number at the top is the priority that the Conditional Activity has over other Combi nodes when there are several Combi nodes linking with a Queue node. A Combi node with a high priority has a chance to start before a Combi node with a lower priority. Priorities can be negative and the default value is zero; for instance, when the priority is not specified it is assumed to be zero. The duration of the activity at the Combi node is determined by the formula at the bottom of the node. The duration formula is randomly sampled from a probability distribution; therefore, different instances of the same Combi node can have different durations. Combi nodes can only follow Queues; however, it can be followed by any other node other than a Combi node (Martinez, 2001).

![Combi Node Example](image)

**Figure 2-2** An example of a Combi node

3) **Bound Activity (Normal Node)**

A Bound Activity (Normal), as shown in figure 2-3, is a modeling element that represents tasks that start whenever an instance of any preceding activity ends. The name of the Normal node, which can be edited by users, is shown at the center. The formula at the bottom of the Normal node is used to determine the
duration of its instances. In the same manner as Combi node, the duration formula is randomly sampled from a probability distribution; therefore, different instances of the same Normal node can have different durations. A Normal node can follow any node except a Queue node, and can precede any node except a Combi node (Martinez, 2001).

![Normal node example](Normal[40,5])

**Figure 2-3 An example of a Normal node**

**4) Draw Link**

A Draw Link, which connects a Queue node to a Combi node, shows two pieces of information separated by a comma. The first part is the condition necessary for the successor Combi node to start as a function of the content of the predecessor Queue node. As seen in Figure 2-4, the text “>0” indicates that the content of the Queue node must be greater than 0 in order to trigger the Combi node to start. There are six relational operators supported by EZStrobe to express this condition: less than (<), less than or equal (<=), greater than (>), greater than or equal (>=), equal (==), and not equal (!=). The second part is the amount of resource that the Combi node will attempt to remove from the predecessor Queue node in the event that the Combi node does start. However, the Combi node may not be able to remove the amount attempted if that amount is greater than the content of the Queue node, in case the entire content is removed (Martinez, 2001).

![Draw Link example](>0, 1)

**Figure 2-4 An example of a Draw Link**
5) **Release Link**

A Release Link connects an activity to any other node except a Combi node. The text shown on a Release Link indicates the amount of resource that will be submitted through the Link each time an instance of the predecessor activity ends (Martinez, 2001). For example, if the text on a Release Link is set at 1, as shown in Figure 2-5, the link will submit 1 unit of resource from the predecessor node to the successive node in the diagram.

![Figure 2-5 An example of a Release Link](image)

6) **Fork Node**

A Fork node, as shown in Figure 2-6, is a probabilistic routing element. It follows an activity but can also follow another Fork node. When a preceding activity is complete, the Fork switches the resource to one of its successors. If the chosen successor is a Normal node then the Normal node starts. However, if the chosen successor is a Queue then the Queue receives any resources routed through the Fork. Somehow, if the chosen successor is another Fork, then the second Fork will choose one of its successors. The relative probability that a particular successor will be chosen depends on the relative probability (P) of the Branch Link, which can be set by users, that derives from the Fork towards the successor (Martinez, 2001).

![Figure 2-6 An example of a Fork Node](image)
7) **Branch Link**

A Branch Link, which is shown in Figure 2-7, can connect a Fork node to any other node except a Combi node. The text shown on a Branch Link indicates the value of the relative probability (P) for that Link. The relative probability (P) establishes the relative probability that the resource will be submitted, every time, to the successor connected by the Branch Link (Martinez, 2001).

![Figure 2-7 An example of a Branch Link](image)

**2.1.2 Coding in EZStrobe**

When deriving results from the model in EZStrobe simulation system, parameter and result bars needs to be created and filled with codes. Coding in EZStrobe is based on the global variables, which refer to their corresponding activity nodes. The results obtained from coding variables through these parameter and result bars will be processed and presented via STROBOSCOPE, when the model is assigned to run. The essential variables used in EZStrobe are illustrated in Table 2-1. When a result bar is created, a shape data box will promptly appear for the user to fill a formula corresponding to the required result. An example of result bar and its shape box are illustrated in Figure 2-8. Similarly, when a result bar is created, a shape data box will promptly appear for the user to fill variables corresponding to the required parameter. An example of parameter bar and its shape box are shown in Figure 2-9.

In order to obtain a complex result, where various parameters are required prior to the calculation, all the related variables need to be created and
programmed with values. Next, an equation of the complex result can be established by referring the name of the related parameters, using dot (.) after the name, and adding the global variables shown in Table 2-1 to obtain the required value. For example, assume that all the related parameters were created and the electricity cost for channel 23 needs to be known, the equation can be established using syntax as seen in equation 2-1, while its result bar is shown in Figure 2-10.

\[ \text{Cost}_{23} = \text{LoadCement}_{23} \cdot \text{TotInst} \times \text{LoadCement}_{23} \cdot \text{AveDur} \times \text{ElectCost} / 60 \quad \ldots (2-1) \]

Table 2-1 Global variables used in EZStrobe software (Martinez, 2001)

<table>
<thead>
<tr>
<th>Variable Form</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SimTime</td>
<td>The current value of the simulation clock</td>
</tr>
<tr>
<td>Activity.AveDur</td>
<td>The average value of the duration of the instances of Activity</td>
</tr>
<tr>
<td>Activity.AveInter</td>
<td>The average inter-instantiation time between instances of Activity</td>
</tr>
<tr>
<td>Activity.CurrInst</td>
<td>The current number of instances of Activity</td>
</tr>
<tr>
<td>Activity.InContext</td>
<td>Returns 1 if an instance of Activity is being created, and 0 otherwise</td>
</tr>
<tr>
<td>Activity.FirstStart</td>
<td>The time at which the first instance of Activity started</td>
</tr>
<tr>
<td>Activity.LastStart</td>
<td>The time at which the last instance of Activity started</td>
</tr>
<tr>
<td>Activity.MaxDur</td>
<td>The maximum value of the durations of the instances of Activity</td>
</tr>
<tr>
<td>Activity.MaxInter</td>
<td>The maximum inter-instantiation times between instances of Activity</td>
</tr>
<tr>
<td>Activity.MinDur</td>
<td>The minimum value of the durations of the instances of Activity</td>
</tr>
<tr>
<td>Activity.MinInter</td>
<td>The minimum inter-instantiation times between instances of Activity</td>
</tr>
<tr>
<td>Activity.SDDur</td>
<td>The standard deviation of the durations of the instances of Activity</td>
</tr>
<tr>
<td>Activity.SDIner</td>
<td>The s.d. of the inter-instantiation times between instances of Activity</td>
</tr>
<tr>
<td>Activity.TotInst</td>
<td>The total number of instances of Activity that have been created</td>
</tr>
<tr>
<td>Queue.LastAmtReceived</td>
<td>The amount of resource that last entered Queue</td>
</tr>
<tr>
<td>Queue.AveCount</td>
<td>The time-weighted average of the content of Queue</td>
</tr>
<tr>
<td>Queue.AveWait</td>
<td>The average waiting time for resources that have entered Queue</td>
</tr>
<tr>
<td>Queue.CurrCount</td>
<td>The current content of Queue</td>
</tr>
<tr>
<td>Queue.MaxCount</td>
<td>The maximum content experienced by Queue</td>
</tr>
<tr>
<td>Queue.MinCount</td>
<td>The minimum content experienced by Queue</td>
</tr>
<tr>
<td>Queue.SDCount</td>
<td>The time-weighted standard deviation of content experienced by Queue</td>
</tr>
<tr>
<td>Queue.TotCount</td>
<td>The total amount of resource that has entered Queue</td>
</tr>
</tbody>
</table>
Figure 2-8 An example of a result bar and its shape data box

Figure 2-9 An example of a parameter bar and its shape data box

Figure 2-10 A result bar of a result involving with several variables
2.2 Key Components of the Queuing Systems

Simulation is more practical and realistic for approaching the queuing system than queuing theory for many reasons. Firstly, the interarrival time distribution may not always be exponential as assumed in queuing theory; therefore, the result prediction should be more accurate when simulation tool is applied to the same problem since the interarrival time distribution can be examined and closely estimated to emulate the real arrival behavior. Secondly, the normal distribution assumption for the service time of servers in queuing theory is occasionally true since, in most case, the distribution may be more fitted to other type of statistical distribution, such as gamma, beta, and Erlang. Consequently, the results of the queuing model could be more accurately predicted when the problem is solved via simulation tool than the use of queuing theory. In addition, compared to queuing theory, the simulation tool is more flexible for modeling queuing problems with high complexity; for example, when the interarrival time is not uniformly distributed, as illustrated by the case in the next chapter of this study. Generally, a queuing system consists of 3 basic components which are: customers, queue, and servers, as illustrated in Figure 2-10.

![Diagram of Basic Components of a Queuing System](image)

Figure 2-11 Basic components of a queuing system
3.1 Cement Loading Process Overview

The process begins when a cement truck arrives at the front office to register the truck driver before proceeding to load cement. Driver’s license plate is checked and matched with information shown in a purchasing order, which is placed at least one day before arriving. Three registration servers, alongside with large parking space assumed to have unlimited capacity for waiting trucks, are provided at this station. Radio-frequency identification (RFID) tag is given to the driver in order to record time that the truck spends in each task, and transfer the data to the database system. Next, the truck is assigned to travel from the parking space to measure its weight at a weighbridge when the queue at loading site, which can withstand the maximum capacity of 40 trucks, is available. There are six weighbridges at this station: three weighbridges are used to measure weight of trucks entering the site and three weighbridges are used to check truck weight after loading cement. By the time that the truck weight is electronically recorded, the truck is automatically assigned to travel to queue at loading site.

The bulk cement loading system consists of ten loading channels, with one cement loading machine in each channel. Only one cement truck can be loaded at a time in each channel. The cement loading channels are categorized into two lines based on queuing system: line 1 and line 2, as their control diagram are shown in Figure A-3 and A-4, respectively. Line 1 consists of four channels: channel 23, channel 24, channel 25, and channel 26, while line 2 consists of six channels: channel 27, channel 28, channel 29, and channel 30, channel 31, and channel 32.
However, nine channels are rotationally used to load cement with one channel, channel 29, normally reserved as a spare to be used in emergency case. When a channel is available, the truck is signaled to proceed to the cement loading channel, which draws Portland cement from its silo. Loading machine operator checks the truck position and automatically attaches the loading machine to the truck. When the truck is fully loaded with 30 tons of cement, it is sealed and signaled to depart from the channel to enter weight measurement station. Although there is a truck scale, embed at the base of each loading channel, to promptly check the cement load, trucks are required to double check their weight at the outlet weighbridges. The cement loading process is done when the truck leaves the outlet weighbridge.

3.2 Statistical Analysis on Parameters

Statistical Analyses were performed based on the raw data, collected during August 28, 2012 and June 3, 2013 by the Asia Cement Plant via RFID tags. The plant is closed during New Year and Thai New Year festivals; therefore, there was no data collected during these periods. In addition, truck arrival rates and waiting time during the days adjacent to the official holidays were extremely low due to relatively low arrival rates, in which the process had no queue; thus, data collected during these days was not included in the analysis in order to avoid effects from special events which may underestimate waiting time and throughput time of the model. Similarly, the data collected during the unexpected shut down time in August 2012 was omitted from the analysis. Consequently, the raw data with population size of 36,689 was used to analyze and calculate parameters for the cement loading process model.
3.2.1 Interarrival Time Characteristics and Distribution Analysis

Interarrival time is duration between successive arrivals of trucks. In most cases, interarrival time is assumed to have an exponential distribution due to convenience (Winston, 2003); however, the statistical distributions of interarrival time of trucks in the cement loading process was examined to test if the interarrival time in this study is consistent with the assumption from queuing theory.

Truck interarrival times were determined by sorting truck arrival times chronologically and subtracting successive arrival time. Then, the interarrival times were grouped and plotted to determine the distribution.

![Interarrival Time Distribution](image)

**Figure 3-1** Statistical distribution of truck interarrival time in cement loading process
The result from ARENA Input Analyzer shows that the interarrival time is exponentially distributed at 0.95 confidence level, as seen in Figure 3-2, with average duration of 9.71 minutes and the corresponding p-value of less than 0.005. In addition, the truck interarrival time distribution in this study is consistent with the queuing theory; however, the result obtained from the analysis is an all-day average interarrival time, in which an effect from the interarrival time fluctuation during the day had not been considered yet. Thus, the interarrival time characteristics was observed in order to determine hourly interarrival times during the day since such a fluctuation could affect the average truck waiting time and machine idle time due to the existence of peak and off-peak periods. In addition, truck arrival characteristics during the week was observed in order to see if there are any differences in truck arrival rates among days in a week. In other words,
effects from peak and off-peak periods to interarrival time were analyzed alongside with an affect from weekdays and weekends.

Table 3-1 Average truck arrival rate of each hour during the day

<table>
<thead>
<tr>
<th>Interval</th>
<th>SUN</th>
<th>MON</th>
<th>TUE</th>
<th>WED</th>
<th>THU</th>
<th>FRI</th>
<th>SAT</th>
<th>Total Arrival</th>
<th>Average Arrival Rate (trucks per hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>00.00-00.59</td>
<td>20</td>
<td>15</td>
<td>20</td>
<td>25</td>
<td>22</td>
<td>27</td>
<td>27</td>
<td>156</td>
<td>3.18</td>
</tr>
<tr>
<td>01.00-01.59</td>
<td>18</td>
<td>24</td>
<td>25</td>
<td>20</td>
<td>23</td>
<td>28</td>
<td>29</td>
<td>167</td>
<td>3.41</td>
</tr>
<tr>
<td>02.00-02.59</td>
<td>27</td>
<td>22</td>
<td>28</td>
<td>26</td>
<td>25</td>
<td>29</td>
<td>49</td>
<td>196</td>
<td>4.00</td>
</tr>
<tr>
<td>03.00-03.59</td>
<td>51</td>
<td>43</td>
<td>27</td>
<td>40</td>
<td>41</td>
<td>42</td>
<td>43</td>
<td>287</td>
<td>5.86</td>
</tr>
<tr>
<td>04.00-04.59</td>
<td>34</td>
<td>31</td>
<td>44</td>
<td>43</td>
<td>46</td>
<td>41</td>
<td>36</td>
<td>275</td>
<td>5.61</td>
</tr>
<tr>
<td>05.00-05.59</td>
<td>38</td>
<td>39</td>
<td>47</td>
<td>45</td>
<td>34</td>
<td>42</td>
<td>44</td>
<td>289</td>
<td>5.90</td>
</tr>
<tr>
<td>06.00-06.59</td>
<td>42</td>
<td>34</td>
<td>41</td>
<td>46</td>
<td>38</td>
<td>52</td>
<td>46</td>
<td>299</td>
<td>6.10</td>
</tr>
<tr>
<td>07.00-07.59</td>
<td>59</td>
<td>37</td>
<td>44</td>
<td>33</td>
<td>44</td>
<td>35</td>
<td>40</td>
<td>292</td>
<td>5.96</td>
</tr>
<tr>
<td>08.00-08.59</td>
<td>42</td>
<td>28</td>
<td>29</td>
<td>44</td>
<td>42</td>
<td>31</td>
<td>39</td>
<td>255</td>
<td>5.20</td>
</tr>
<tr>
<td>09.00-09.59</td>
<td>46</td>
<td>24</td>
<td>24</td>
<td>19</td>
<td>30</td>
<td>34</td>
<td>52</td>
<td>229</td>
<td>4.67</td>
</tr>
<tr>
<td>10.00-10.59</td>
<td>37</td>
<td>37</td>
<td>35</td>
<td>30</td>
<td>37</td>
<td>30</td>
<td>40</td>
<td>246</td>
<td>5.02</td>
</tr>
<tr>
<td>11.00-11.59</td>
<td>48</td>
<td>34</td>
<td>16</td>
<td>33</td>
<td>26</td>
<td>35</td>
<td>42</td>
<td>234</td>
<td>4.78</td>
</tr>
<tr>
<td>12.00-12.59</td>
<td>45</td>
<td>31</td>
<td>43</td>
<td>40</td>
<td>39</td>
<td>30</td>
<td>36</td>
<td>264</td>
<td>5.39</td>
</tr>
<tr>
<td>13.00-13.59</td>
<td>37</td>
<td>70</td>
<td>73</td>
<td>78</td>
<td>75</td>
<td>87</td>
<td>58</td>
<td>478</td>
<td>9.76</td>
</tr>
<tr>
<td>14.00-14.59</td>
<td>65</td>
<td>94</td>
<td>73</td>
<td>83</td>
<td>100</td>
<td>79</td>
<td>56</td>
<td>550</td>
<td>11.22</td>
</tr>
<tr>
<td>15.00-15.59</td>
<td>80</td>
<td>85</td>
<td>83</td>
<td>94</td>
<td>97</td>
<td>91</td>
<td>66</td>
<td>596</td>
<td>12.16</td>
</tr>
<tr>
<td>16.00-16.59</td>
<td>72</td>
<td>80</td>
<td>62</td>
<td>59</td>
<td>91</td>
<td>84</td>
<td>65</td>
<td>513</td>
<td>10.47</td>
</tr>
<tr>
<td>17.00-17.59</td>
<td>51</td>
<td>71</td>
<td>66</td>
<td>62</td>
<td>59</td>
<td>51</td>
<td>44</td>
<td>404</td>
<td>8.24</td>
</tr>
<tr>
<td>18.00-18.59</td>
<td>39</td>
<td>44</td>
<td>56</td>
<td>51</td>
<td>50</td>
<td>45</td>
<td>41</td>
<td>326</td>
<td>6.65</td>
</tr>
<tr>
<td>19.00-19.59</td>
<td>40</td>
<td>62</td>
<td>47</td>
<td>47</td>
<td>57</td>
<td>49</td>
<td>26</td>
<td>328</td>
<td>6.69</td>
</tr>
<tr>
<td>20.00-20.59</td>
<td>30</td>
<td>51</td>
<td>49</td>
<td>42</td>
<td>40</td>
<td>45</td>
<td>35</td>
<td>292</td>
<td>5.96</td>
</tr>
<tr>
<td>22.00-22.59</td>
<td>15</td>
<td>20</td>
<td>19</td>
<td>27</td>
<td>22</td>
<td>23</td>
<td>26</td>
<td>152</td>
<td>3.10</td>
</tr>
<tr>
<td>Total</td>
<td>984</td>
<td>1,018</td>
<td>1,025</td>
<td>1,053</td>
<td>1,099</td>
<td>1,072</td>
<td>1,002</td>
<td>7,253</td>
<td>148.02</td>
</tr>
</tbody>
</table>
Truck arrival rates for each 1-hour period during the day were determined by sampling 49 days, as observations, out of the total 268 days. Next, the analysis was performed by sorting arrival times chronologically, grouping them into categories, and finding average truck arrival rates for each 1-hour period.

The analysis, as seen in Table 3-1, shows that the average arrival rate is 148 trucks per day. The result was found to be consistent with the result from ARENA Input Analyzer since it implies that the average interarrival time from sampling is 9.73 minutes, which yields only 0.2% of error; thus, the sample can be used to represent the population.

![Average Hourly Truck Arrival Rate Categorized by Day](image)

**Figure 3-3** Average hourly truck arrival rates categorized by day
Average truck arrival rates during each hour on each day were summarized to obtain arrival characteristics during 24-hour period, as seen in Figure 3-3. Obviously, arrival characteristics of trucks during weekdays and weekends seem to perform in similar manner, as shown in Figure 3-4. However, to double check the assumption, average truck arrival rates during weekday and weekend were compared to see if there is a difference between average arrival rates of weekdays and weekends. To do so, the two-sample means z-test was conducted on the hourly average arrival rates of the same sample, which the summarized data is shown in Table 3-2.
Table 3-2 Average truck arrival rates and total arrival classified by day

<table>
<thead>
<tr>
<th>Interval</th>
<th>Weekday Arrival Rates</th>
<th>Weekend Arrival Rates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Monday</td>
<td>Tuesday</td>
</tr>
<tr>
<td>00.00-00.59</td>
<td>2.14</td>
<td>2.86</td>
</tr>
<tr>
<td>01.00-01.59</td>
<td>3.43</td>
<td>3.57</td>
</tr>
<tr>
<td>02.00-02.59</td>
<td>2.14</td>
<td>4.00</td>
</tr>
<tr>
<td>03.00-03.59</td>
<td>3.14</td>
<td>6.00</td>
</tr>
<tr>
<td>04.00-04.59</td>
<td>6.14</td>
<td>3.86</td>
</tr>
<tr>
<td>05.00-05.59</td>
<td>4.43</td>
<td>6.29</td>
</tr>
<tr>
<td>06.00-06.59</td>
<td>5.57</td>
<td>6.71</td>
</tr>
<tr>
<td>07.00-07.59</td>
<td>4.86</td>
<td>5.86</td>
</tr>
<tr>
<td>08.00-08.59</td>
<td>5.29</td>
<td>6.29</td>
</tr>
<tr>
<td>09.00-09.59</td>
<td>4.00</td>
<td>4.14</td>
</tr>
<tr>
<td>10.00-10.59</td>
<td>3.43</td>
<td>3.43</td>
</tr>
<tr>
<td>11.00-11.59</td>
<td>5.29</td>
<td>5.00</td>
</tr>
<tr>
<td>12.00-12.59</td>
<td>4.86</td>
<td>2.29</td>
</tr>
<tr>
<td>13.00-13.59</td>
<td>4.43</td>
<td>6.14</td>
</tr>
<tr>
<td>14.00-14.59</td>
<td>10.00</td>
<td>10.43</td>
</tr>
<tr>
<td>15.00-15.59</td>
<td>13.43</td>
<td>10.43</td>
</tr>
<tr>
<td>16.00-16.59</td>
<td>12.14</td>
<td>11.86</td>
</tr>
<tr>
<td>17.00-17.59</td>
<td>11.43</td>
<td>8.86</td>
</tr>
<tr>
<td>18.00-18.59</td>
<td>10.14</td>
<td>9.43</td>
</tr>
<tr>
<td>19.00-19.59</td>
<td>6.29</td>
<td>8.00</td>
</tr>
<tr>
<td>20.00-20.59</td>
<td>8.86</td>
<td>6.71</td>
</tr>
<tr>
<td>21.00-21.59</td>
<td>7.29</td>
<td>7.00</td>
</tr>
<tr>
<td>22.00-22.59</td>
<td>3.86</td>
<td>4.57</td>
</tr>
<tr>
<td>23.00-23.59</td>
<td>2.86</td>
<td>2.71</td>
</tr>
<tr>
<td>SUM</td>
<td>145.43</td>
<td>146.43</td>
</tr>
</tbody>
</table>

Figure 3-5 shows average truck arrival rates per day for each day in a week. The truck arrival rates range from 141 – 157 trucks per day, with an average of 148 trucks per day, as shown at the bottom of Table 3-3. The analysis shows that there is no significant difference between the means of average weekday arrival rate and average weekend arrival rate at 0.95 confidence level since the p-value is equal to 0.36 for the two-tail z-test, where the critical z value is ±1.96. The average
weekday arrival rate, obtained from 120 observations, was found to be 6.27 trucks per hour with variance of 8.59 while the average weekend arrival rate, obtained from 48 observations, equals 5.91 trucks per hour with variance of 3.98. Consequently, the arrival rates of trucks during weekdays and weekends of the simulation models in this study are assumed to have the same characteristic.

Figure 3-5 Average daily truck arrival rates categorized by day
Average truck arrival rates during each 1-hour period were plotted to see arrival characteristics of trucks at the cement plant. Obviously, the truck arrival rate is not steady over time since a peak curve is found, as shown in Figure 3-6. The highest arrival rate was found to be during 16.00 – 16.59, with average arrival rate of 12.16 trucks per hour, while 6.17 trucks per hour is the average truck arrival rate of all periods combined. The lowest arrival rate was found to occur during 23.00 – 23.59, with average arrival rate of 3.10 trucks per hour. The graph shows that the arrival rate dramatically shifts from 5.93 trucks per hour during 13.00 – 13.59 interval to 9.76 trucks per hour during 14.00 – 14.59 interval.

The arrival rate seems to gradually climb from 3.18 trucks per hour during 00.00 – 00.59 interval to 5.86 trucks per hour during 04.00 – 04.59. During 5.00 – 13.59, the truck arrival rate seems to have small fluctuations over time; however, it dramatically surges to 9.76 trucks per hour during 14.00 – 14.59 interval. The
arrival rate stays extremely high during 14.00 – 18.59, by considering shoulders of the peak period, forming a peak period of the day with average arrival rate of 10.37 trucks per hour. Although the arrival rate drops from 8.24 trucks per hour during 18.00 – 18.59 to 6.65 during 19.00 – 19.59, the arrival rate stays moderately high from 19.00 to 22.00 at 6.0 to 6.7 trucks per hour, which is approximately equal to the all-day average. The arrival rate drops to the lowest arrival rate again during 22.00 – 02.59, forming an off-peak period since most of the arrival rates during this period are equal to or lower than 4 trucks per hour. The remaining period, to say, 03.00 – 13.59 and 19.00 – 21.59 are considered as AM mid-peak and PM mid-peak periods, respectively, due to the moderate truck arrival rates.

Consequently, truck arrival rate was classified into 4 phases in order to simulate the behavior of truck arrival characteristics during the day. The 5-hour long peak period starts from 14.00 to 18.59, while the 5-hour long off-peak period starts from 22.00 – 02.59. The AM mid-peak period and PM mid-peak period have durations of 11 hours and 3 hours, respectively. As a result of the division, interarrival times of the off-peak period, AM mid-peak period, peak period, and PM peak period were found to be 16.84 minutes, 11.18 minutes, 5.93 minutes, and 9.32 minutes, respectively, as seen in Table 3-3.
Table 3-3 Average truck arrival rate, interarrival time, and total arrival during each phase

<table>
<thead>
<tr>
<th>Phase</th>
<th>Average Arrival Rate (trucks/hour)</th>
<th>Average Interarrival Time (minutes)</th>
<th>Average Arrival (trucks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Off-peak period</td>
<td>3.56</td>
<td>16.84</td>
<td>18</td>
</tr>
<tr>
<td>AM mid-peak period</td>
<td>5.37</td>
<td>11.18</td>
<td>59</td>
</tr>
<tr>
<td>Peak period</td>
<td>10.37</td>
<td>5.93</td>
<td>52</td>
</tr>
<tr>
<td>PM mid-peak period</td>
<td>6.44</td>
<td>9.32</td>
<td>19</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>148</td>
</tr>
</tbody>
</table>

At this point, the interarrival time distribution and the distribution pattern of the average number of total arrival during each period need to be determined as a stepping stone to simulate the arrival characteristics of trucks; thus, further analyses were done to obtain such results.

**Off-Peak Period**

In order to determine the interarrival time distribution of the off-peak period, 2008-sample-size interarrival time data during 10.00 PM to 02.59 AM was randomly picked from the data pool, classified into intervals, and summarized by using ARENA Input Analyzer. The result from ARENA Input Analyzer shows that the interarrival time of the off-peak period is fit to exponential distribution, with average duration of 16.8 minutes and the corresponding p-value of less than 0.01, according to Kolmogorov-Smirnov Test, as shown in Figure 3-7 and Figure 3-8. The expression of interarrival time during the off-peak period can be found using equation 3-1.

\[
\text{Interarrival Time} = \text{Exponential}[16.8] \quad \ldots (3-1)
\]
Figure 3-7 Interarrival time distribution result of the off-peak period from ARENA Input Analyzer

Figure 3-8 Statistical distribution of truck interarrival time during off-peak period
Figure 3-9 Distribution of total truck arrival during the off-peak period from ARENA Input Analyzer

The number of truck arrived during the 5-hour off-peak period, obtained from 49 days, was found to have gamma distribution, with the corresponding p-value from Chi square test of 0.019, as seen in Figure 3-9. The expression of average number of truck arrived during the off-peak period can be found using equation 3-2.

\[
Total\ Arrival = Int[5 + Gamma(7.36, 1.67)]
\] ... (3-2)

AM Mid-Peak Period

Interarrival time distribution of the AM mid-peak period was determined by sampling 2,815 interarrival time data during 03.00 AM to 01.59 PM to be classified into intervals, and summarized by using ARENA Input Analyzer. The result from ARENA Input Analyzer shows that the interarrival time of the off-peak period is fit to exponential distribution, with average duration of 11.18 minutes and
the corresponding p-value of less than 0.01, according to Kolmogorov-Smirnov Test, as shown in Figure 3-10 and Figure 3-11. The expression of interarrival time during the AM m-peak period can be found using equation 3-3.

\[
\text{Interarrival Time} = \text{Exponential}[11.2]
\]  \hspace{1cm} \text{... (3-3)}

The number of truck arrived during the 11-hour AM mid-peak period, obtained from 49 days, was found to have triangular distribution, with the corresponding p-value of less than 0.005, as seen in Figure 3-12. The expression of average number of truck arrived during the AM mid-peak period can be found using equation 3-4.

\[
\text{Total Arrival} = \text{Int}[\text{Triangular}[40, 63, 87]]
\]  \hspace{1cm} \text{... (3-4)}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure3.png}
\caption{Interarrival time distribution result of the AM mid-peak period from ARENA Input Analyzer}
\end{figure}
Figure 3-11 Statistical distribution of truck interarrival time during AM mid-peak period

Figure 3-12 Distribution of total truck arrival during the AM mid-peak period from ARENA Input Analyzer

36
Peak Period

In order to determine the interarrival time distribution of the peak period, 2,147-sample-size interarrival time data during 02.00 PM to 06.59 PM was randomly chosen from the data pool, classified into intervals, and summarized by using ARENA Input Analyzer. The result from ARENA Input Analyzer shows that the interarrival time of the off-peak period is fit to exponential distribution, with average duration of 5.9 minutes and the corresponding p-value of less than 0.01, according to Kolmogorov-Smirnov Test, as shown in Figure 3-13 and Figure 3-14. The expression of interarrival time during the peak period can be found using equation 3-5.

\[ \text{Interarrival Time} = \text{Exponential}[5.9] \]  \[ \text{... (3-5)} \]

The total number of truck arrived during the 5-hour peak period, obtained from 49 days, was found to have triangular distribution, with the corresponding p-value of less than 0.005, as seen in Figure 3-15. The expression of average number of truck arrived during the peak period can be found using equation 3-6.

\[ \text{Total Arrival} = \text{Int} [\text{Triangular}[25, 55, 73]] \]  \[ \text{... (3-6)} \]
Figure 3-13 Interarrival time distribution result of the peak period from ARENA Input Analyzer

Figure 3-14 Statistical distribution of truck interarrival time during the peak period
Interarrival time data during 07.00 PM to 09.59 PM of 1,817 sample size was randomly chosen from the data pool, classified into intervals, and summarized by using ARENA Input Analyzer, in order to determine the interarrival time distribution of the peak period. The result from ARENA Input Analyzer shows that the interarrival time of the PM mid-peak period is fit to exponential distribution, with average duration of 9.33 minutes and the corresponding p-value of less than 0.005, according to Chi Square Test, as shown in Figure 3-16 and Figure 3-17. The expression of interarrival time during the PM mid-peak period can be found using equation 3-7.

\[ \text{Interarrival Time} = \text{Exponential}[9.33] \quad \ldots (3-7) \]
The number of truck arrived during the 3-hour PM mid peak period, collected from 49 days, was found to have uniform distribution, with the corresponding p-value of less than 0.005, as seen in Figure 3-18. The expression of average number of truck arrived during the PM mid-peak period can be found using equation 3-8.

\[ Total\ Arrival = \text{Int} \left[ \text{Uniform} [11,32] \right] \] \hspace{1cm} \ldots (3-8)

Figure 3-16 Interarrival time distribution result of the PM mid-peak period from ARENA Input Analyzer
Figure 3-17 Statistical distribution of truck interarrival time during the PM mid-peak period

Figure 3-18 Distribution of total truck arrival during the PM mid-peak period from ARENA Input Analyzer
3.2.2 Cement Loading Time Analysis

The cement loading system consists of ten loading channels, with one cement loading machine in each channel. The cement loading channels are categorized into two lines based on queuing system, as seen in Table 3-4. Line 1 consists of four channels: channel 23, channel 24, channel 25, and channel 26, while line 2 consists of six channels: channel 27, channel 28, channel 29, and channel 30, channel 31, and channel 32. However, nine channels are rotationally used to load cement with one channel, channel 29, normally reserved as a spare to be used in emergency case.

Table 3-4 Average truck arrival rate, interarrival time, and total arrival during each phase

<table>
<thead>
<tr>
<th>Queue</th>
<th>Loading Channel</th>
<th>Average Loading Time (minutes)</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line 1</td>
<td>23</td>
<td>19.41</td>
<td>7.47</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>18.84</td>
<td>6.70</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>22.54</td>
<td>8.31</td>
</tr>
<tr>
<td></td>
<td>26</td>
<td>22.47</td>
<td>7.75</td>
</tr>
<tr>
<td>Line 2</td>
<td>27</td>
<td>28.61</td>
<td>9.63</td>
</tr>
<tr>
<td></td>
<td>28</td>
<td>28.05</td>
<td>10.22</td>
</tr>
<tr>
<td></td>
<td>29</td>
<td>29.07</td>
<td>9.68</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>22.78</td>
<td>8.43</td>
</tr>
<tr>
<td></td>
<td>31</td>
<td>25.58</td>
<td>9.93</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>22.90</td>
<td>9.16</td>
</tr>
</tbody>
</table>

To find loading time for each channel, firstly, cement loading time data during August 28, 2012 to June 3, 2013 was categorized into 10 groups, by channels where trucks were loaded. Next, the average loading time of each channel and its standard deviation time were calculated. Finally, loading time distribution patterns of each channel was determined, by using ARENA Input Analyzer as a tool, in order to be used in the simulation models. Such distributions are shown on the next page.
Loading Time of Channel 23

There were 2,699 trucks loaded cement with channel 23 during the study period. To determine loading time distribution pattern of channel 23, the data was summarized using ARENA Input Analyzer. The result shows that the loading time of the channel 23 is fit to gamma distribution, with average duration of 19 minutes and the corresponding p-value of less than 0.005, according to Chi Square Test, as shown in Figure 3-19. The expression of loading time of channel 23 is represented by equation 3-9.

\[
\text{Loading Time (23)} = 10 + \text{Gamma}[6.26, 1.43]
\] ... (3-9)

Figure 3-19 Loading time distribution result of channel 23 from ARENA Input Analyzer
Loading Time of Channel 24

There were 2,488 trucks loaded cement with channel 24 during the study period. To determine loading time distribution pattern of channel 24, the data was summarized using ARENA Input Analyzer. The result shows that the loading time of the channel 24 is fit to gamma distribution, with average duration of 18.8 minutes and the corresponding p-value of less than 0.005, according to Chi Square Test, as shown in Figure 3-20. The expression of loading time of channel 24 is represented by equation 3-10.

\[
\text{Loading Time (24)} = 10 + \text{Gamma}[4.94, 1.79]
\]  \hspace{1cm} \ldots (3-10)

Figure 3-20 Loading time distribution result of channel 24 from ARENA Input Analyzer
Loading Time of Channel 25

There were 3,646 trucks loaded cement with channel 25 during the study period. To determine loading time distribution pattern of channel 25, the data was summarized using ARENA Input Analyzer. The result shows that the loading time of the channel 25 is fit to gamma distribution, with average duration of 22.5 minutes and the corresponding p-value of less than 0.005, according to Chi Square Test, as shown in Figure 3-21. The expression of loading time of channel 25 is represented by equation 3-11.

\[
\text{Loading Time (25)} = 12 + \text{Gamma}[7.86, 1.34]
\]  

\text{... (3-11)}

Figure 3-21 Loading time distribution result of channel 25 from ARENA Input Analyzer
Loading Time of Channel 26

There were 2,305 trucks loaded cement with channel 26 during the study period. To determine loading time distribution pattern of channel 26, the data was summarized using ARENA Input Analyzer. The result shows that the loading time of the channel 26 is fit to gamma distribution, with average duration of 22.5 minutes and the corresponding p-value of less than 0.005, according to Chi Square Test, as shown in Figure 3-22. The expression of loading time of channel 26 is represented by equation 3-12.

\[
\text{Loading Time} (26) = 11 + \text{Gamma}[6.08, 1.89]
\]  

... (3-12)

![Distribution Summary](image)

Figure 3-22 Loading time distribution result of channel 26 from ARENA Input Analyzer
Loading Time of Channel 27

There were 2,305 trucks loaded cement with channel 27 during the study period. To determine loading time distribution pattern of channel 27, the data was summarized using ARENA Input Analyzer. The result shows that the loading time of the channel 27 is fit to gamma distribution, with average duration of 28.6 minutes and the corresponding p-value of less than 0.005, according to Chi Square Test, as shown in Figure 3-23. The expression of loading time of channel 27 is represented by equation 3-13.

\[
\text{Loading Time (27)} = 15 + \text{Gamma}[9.05, 1.5]
\]  

... (3-13)

![Figure 3-23 Loading time distribution result of channel 27 from ARENA Input Analyzer](image)
Loading Time of Channel 28

There were 1,635 trucks loaded cement with channel 28 during the study period. To determine loading time distribution pattern of channel 28, the data was summarized using ARENA Input Analyzer. The result shows that the loading time of the channel 28 is fit to gamma distribution, with average duration of 28 minutes and the corresponding p-value of less than 0.005, according to Chi Square Test, as shown in Figure 3-24. The expression of loading time of channel 28 is represented by equation 3-14.

\[
\text{Loading Time (28)} = 11 + \text{Gamma}[7.39, 2.31] \quad \ldots (3-14)
\]

Figure 3-24 Loading time distribution result of channel 28 from ARENA Input Analyzer
Loading Time of Channel 30

There were 5,690 trucks loaded cement with channel 30 during the study period. To determine loading time distribution pattern of channel 30, the data was summarized using ARENA Input Analyzer. The result shows that the loading time of the channel 30 is fit to gamma distribution, with average duration of 22.8 minutes and the corresponding p-value of less than 0.005, according to Chi Square Test, as shown in Figure 3-25. The expression of loading time of channel 30 is represented by equation 3-15.

\[
\text{Loading Time (30)} = 10 + \text{Gamma}[5.78, 2.21] \tag{3-15}
\]

![Figure 3-25 Loading time distribution result of channel 30 from ARENA Input Analyzer](image)
Loading Time of Channel 31

There were 5,206 trucks loaded cement with channel 31 during the study period. To determine loading time distribution pattern of channel 31, the data was summarized using ARENA Input Analyzer. The result shows that the loading time of the channel 31 is fit to gamma distribution, with average duration of 25 minutes and the corresponding p-value of less than 0.005, according to Chi Square Test, as shown in Figure 3-26. The expression of loading time of channel 31 is represented by equation 3-16.

\[\text{Loading Time} (31) = 10 + \text{Gamma}[7.68, 1.82]\]  

... (3-16)

![Figure 3-26 Loading time distribution result of channel 31 from ARENA Input Analyzer](image)
Loading Time of Channel 32

There were 5,904 trucks loaded cement with channel 32 during the study period. To determine loading time distribution pattern of channel 32, the data was summarized using ARENA Input Analyzer. The result shows that the loading time of the channel 32 is fit to gamma distribution, with average duration of 22.9 minutes and the corresponding p-value of less than 0.005, according to Chi Square Test, as shown in Figure 3-27. The expression of loading time of channel 32 is represented by equation 3-17.

\[
\text{Loading Time (32)} = 10 + \text{Gamma}(7.68, 1.82)
\]  
\[ ... (3-17) \]

![Figure 3-27 Loading time distribution result of channel 32 from ARENA Input Analyzer](image)
3.2.3 Processing Times Analysis

In this study, the process starts when a cement truck arrives at the front office and proceeds to the registration process. At this stage, the driver’s license plate is checked and matched with information shown in a purchasing order. Three registration servers are provided at this station. Unlike loading time, the registration time is not solely reflected by the operators’ performance since each truck enters the system may require various durations to complete this stage, depend on many factors such as documents, drivers’ punctuality, and climate conditions; thus, it might not be fluctuated from server to server due to this factor rather than from truck to truck. Thereby, the registration time duration is considered as chaos and assumed for each truck in the simulation model in random manner. In addition, the parking space attached to the registration office is assumed to have unlimited capacity for waiting trucks in the model due to its large size that the capacity has never been exceeded, according to the record.

The result from ARENA Input Analyzer based on 36,689 data point indicates that the registration time is fit to gamma distribution with mean of 8.96 minutes per truck, as seen in Figure 3-28. The result is significant at 0.95 confidence level since the corresponding p-value is found to be less than 0.005, according to Chi Square Test. The stream number 20 was used in the model to generate sets of random number for the registration time. Thus, the expression of registration time can be represented by equation 3-18.

\[
\text{Registration Time} = \text{Gamma}[17.7, 0.506, 20]
\]  \quad \ldots (3-18)
When the queue lines at the cement loading site, which can withstand the maximum capacity of 40 trucks, is available, the truck is assigned to travel from the parking space to measure its weight at a weighbridge.

The result from ARENA Input Analyzer based on 36,689 data point shows that the truck proceeding time from the parking space to weighbridge is best-fit to Erlang distribution with an Erlang parameter of 7 and mean of 3.79 minutes per truck, as seen in Figure 3-29. The result is significant at 0.95 confidence level since the corresponding p-value is found to be less than 0.005, according to Chi Square Test. The stream number 20 was used in the model to generate sets of random
number for the registration time. Thus, the expression of truck proceeding time can be represented by equation 3-19.

\[ \text{Truck Proceed Time} = \text{Erlang} \{7, 3.79, 20\} \quad \ldots \ (3-19) \]

Figure 3-29 Truck proceeding time distribution result from ARENA Input Analyzer

There are three weighbridges, which are randomly used to measure weight of trucks entering the site. The truck weight is electronically recorded when the truck stays on the weighbridge. After the truck is loaded, it is automatically assigned to travel to queue at cement loading site. Time is recorded by using Radio-frequency identification (RFID) tag attached to the truck to transfer the time data to the database system.
The result from ARENA Input Analyzer based on 3,876 sample size shows that the inlet weight measuring time is best-fit to Erlang distribution with an Erlang parameter of 1 and mean of 0.34 minutes per truck, as seen in Figure 3-30. The result is significant at 0.95 confidence level since the corresponding p-value is found to be less than 0.005, according to Chi Square Test. The stream number 20 was used in the model to generate sets of random number for the registration time. Thus, the expression of truck proceeding time can be represented by equation 3-20.

\[
\text{Inlet Weight Measuring Time} = \text{Erlang} [1, 0.34, 20]
\]  \text{... (3-20)}
The result from ARENA Input Analyzer based on 32,229 sample size shows that travel time from the weighbridge to the queue at loading site is best-fit to Erlang distribution with an Erlang parameter of 1 and mean of 1.46 minutes per truck, as seen in Figure 3-31. The result is significant at 0.95 confidence level since the corresponding p-value is found to be less than 0.005, according to Chi Square Test. The stream number 20 was used in the model to generate sets of random number for the registration time. Thus, the expression of truck proceeding time can be represented by equation 3-21.

\[
Travel Time \text{ (in)} = Erlang \left[1, 1.46, 20\right] \quad \ldots (3-21)
\]

Figure 3-31 Distribution result of travel time to queue from ARENA Input Analyzer
When the truck is fully loaded with 30 tons of cement, it is sealed and signaled to depart from the loading channel to enter weight measurement station. By the time the sealing process starts, another truck waiting at the waiting space is called to proceed to enter the cement loading site.

The result from ARENA Input Analyzer based on 36,689 data points shows that sealing time is best-fit to Erlang distribution with an Erlang parameter of 1 and mean of 1.42 minutes per truck, as seen in Figure 3-32. The result is significant at 0.95 confidence level since the corresponding p-value is found to be less than 0.005, according to Chi Square Test. The stream number 2 was used in the model to generate sets of random number for the registration time. Thus, the expression of truck proceeding time can be represented by equation 3-22.

\[
\text{Sealing Time} = -0.001 + \text{Erlang}[1, 1.42, 2]
\]

\[\text{... (3-22)}\]

Figure 3-32 Sealing time distribution result from ARENA Input Analyzer
As soon as the sealing process is complete, the truck travels to the outlet weight bridge to double check its load. Although the distance between each loading channel and the weighbridge varies from channel to channel, the travel time for each truck in this study is assumed not to be significantly reflected by such distances since the loading channels are adjacent to each other and travel speed is limited to 30 kilometers per hour; thus, the differences in travel times from various loading channel to weighbridge are very small and could be neglected.

The result from ARENA Input Analyzer based on 36,689 data points shows that sealing time is best-fit to Erlang distribution with an Erlang parameter of 4 and mean of 0.713 minutes per truck, as seen in Figure 3-33. The result is significant at 0.95 confidence level since the corresponding p-value is found to be less than 0.005, according to Chi Square Test. The stream number 2 was used in the model to generate sets of random number for the registration time. Thus, the expression of truck proceeding time can be represented by equation 3-23.

\[ Travel\ Time\ (out) = Erlang\ [4, 0.713, 2] \] ... (3-23)
There are three weighbridges, which are randomly used to double check weight of trucks loaded with cement. After cement load is checked, the truck is allowed to exit from the plant and the cement loading process is end.

The result from ARENA Input Analyzer based on 31,735 data points shows that sealing time is best-fit to exponential distribution mean of 0.33 minute per truck, as seen in Figure 3-34. The result is significant at 0.95 confidence level since the corresponding p-value is found to be less than 0.005, according to Chi Square Test. The stream number 9 was used in the model to generate sets of random number for the registration time. Thus, the expression of truck proceeding time can be represented by equation 3-24.

\[
\text{Outlet Weight Measuring Time} = \text{Exponential} [0.33, 9] \quad \ldots \ (3-24)
\]
Figure 3-34 Distribution result of outlet weight checking time from ARENA Input Analyzer
The current practice of the bulk cement loading process was simulated by using parameters based on statistical distributions, which were analyzed in the previous chapter. EZStrobe simulation software was applied as a virtual medium to create the cement loading process model. The purpose of creating this model is that to create a prototype and see reliability of the model, by comparing the results from simulation to the actual data from the real practice, for the sake of creating improved models based on this prototype. As a result, model validation was conducted at the end of this section.

4.1 Truck Arrival Characteristics Simulation

The truck arrival model was created based on the analysis in section 3.2.1 that the arrival characteristic of trucks was estimated to have 4 phases: off-peak period, AM mid-peak period, peak period, and PM mid peak period.

The simulation starts at the Generate queue node, acting like a truck generator and performing in birth-death manner, when it generates trucks to the system and receives them back after they complete the whole process. The Generate Queue node starts with an initial amount of 50,000 trucks, which is sufficient to make the model run smoothly without lacking of resources. The model is set to start on the off-peak period when Create1 Queue node, Generate Queue node, and Dummy1 Queue node promptly send resources to Inter1 Combi node, which the duration is equal to off-peak interarrival time, as seen in Figure 4-1. Each truck arrives to the system at TruckArrive Queue node every time when task at the Inter1 Combi node is complete. The off-peak period runs until the Con1
Queue node consolidates the number of trucks equal to \( n_{\text{Truck1}} \), which is the generated number of trucks arrive during off-peak period, based on the statistical distribution analyzed in the previous section.

Next, the Dummy1 Queue node shifts to switch the Inter2 Combi node on to start the AM mid-peak period until the total amount of trucks at Con2 Queue node is equal to \( n_{\text{Truck2}} \). Then the Dummy1 Queue node switches to Inter3 and Inter4 Combi nodes, respectively, to simulate truck arrival characteristics during peak period and PM mid-peak period, until Con3 and Con4 consolidate the total number of trucks equal to \( n_{\text{Truck3}} \) and \( n_{\text{Truck4}} \), respectively. The Dummy1 Queue node, then, switches to the Inter1 Combi node again to complete one loop of the truck arrival model.
Figure 4-1 Truck arrival characteristics simulation model from EZStrobe
4.2 Process Simulation

Once a truck is generated by the truck arrival characteristics model, it is sent to ArrivalRecord Combi node and FrontOffice Queue node, respectively, to enter the cement loading process, as shown in Figure 4-2. The truck proceeds to TruckRegister Combi node when the resource at Registrar Queue node, which an initial content is set to 3 to simulate the number of registrar, is available.

After the registration task is complete, the truck is submitted to TruckWait Queue node to stand by, and progress to TruckProceed Combi node when the value of available space units at Space_Available Queue node is positive. An initial content of the Space_Available Queue node is set to 40 to simulate the available space units at the cement loading site.

When the task at TruckProceed Combi node is complete, one unit of truck is sent to WeightQueue to be ready for progressing to weighbridge, while one unit of resource from Space_Available Queue node is submitted to Call Queue node as an order to occupy a unit of space for this truck at the cement loading site. Hence, Weighbridge1 Queue node sends one resource, if available, to switch the MeasureWeight1 Combi node on. The initial content of the Weighbridge1 Queue node is equal to 3 since there are 3 weighbridges available at this station.

After the task at the weighbridge is done, the truck proceeds to the cement loading site by performing the TruckTravel_In Normal node and proceeding to TruckQueue node, respectively. At this point, the truck proceeds to queue and load cement at cement loading site; however, the simulation model of such a system will be skipped to be explained in the next section due to continuity of the process and complexity of the model.
Figure 4-2 Process simulation model from EZStrobe
When the truck is fully loaded with 30 tons of cement, it proceeds to be sealed at a position adjacent to the loading position; therefore, the next truck in the queue can immediately progress to the loading channel and head to a weighbridge, respectively. Regarding these steps, when the truck arrives at the Loaded Queue node after completing a task at loading channel, it is promptly sent to Sealing Combi node and TruckTravel_Out Normal node, in an orderly fashion, as seen in Figure 4-2.

Next, the truck is waited at the OutQueue node, if needed, in order to be ready to enter a weighbridge at MeasureWeight2 Combi node, according to the model. Once again, there are 3 weighbridges available at this station; therefore, an initial content of 3 is set for the Weighbridge2 Queue node, which transfers one unit of resource to the MeasureWeight2 node each time when a truck arrives at the OutQueue node.

When the task at MeasureWeight2 node is done, the truck is sent to Count Normal node to depart from the system and record its throughput time, while the occupied weighbridge is available when the resource is returned to Weighbridge2 Queue node. Finally, the truck is returned to the pool at the Generate queue node.

4.3 Queuing and Cement Loading Characteristics Simulations

Before cement loading characteristics of the process is explained, firstly, queuing characteristics of the system shall be illustrated since it is a preceding step of the process at cement loading site. The cement loading model starts when a truck enters the cement loading site.

According to the model, the cement loading model begins when the TruckQueue node in the process model, as shown in Figure 3-36, receives one unit of truck, and automatically transfers it to its fusion node in the cement loading
model, which is illustrated in Figure 4-3. Meanwhile, the Call Queue node, possessing 1 unit of space for the truck, promptly submits its resource to the Enter Combi node to signal that the space at the site is reserved. Hence, the truck proceeds to the Enter Combi node and immediately quits since the Combi node is established as a bypass for those 2 types of entities: truck and space. Next, the space resource is sent to SpaceOccupied Queue node to indicate that the space at the site is completely occupied, while the truck deals with a dilemma due to the queue it was assigned. According to the randomly sampled queuing data from 8,062 trucks during 54 days, it is found that the probability that a truck is assigned to the queue line 1, in which 4 loading channels are served, is 39.95% while the probability that a truck is assigned to the queue line 2, in which 5 loading channels are available, is 60.05%. As a result, a fork node is created adjacent to the Enter Combi node to classify each truck to its queue, consistently with the parameters from the analysis, in order to simulate the queuing characteristics of the system. Therefore, the cement loading model is programmed to serve trucks in first-come-first-serve manner with 2 queue lines provided: QueueLine1 and QueueLine2, as seen in Figure 4-3.

![Figure 4-3 Queuing characteristics model from EZStrobe](image-url)
Figure 4-4 Cement loading system of queue line 1 from EZStrobe
Figure 4-5 Cement loading system of queue line 2 from EZStrobe
4.3.1 Simulation Model of Queue Line 1

If a truck is assigned to queue in the queue line 1, the possible loading channels that the truck can enter are channel 23, channel 24, channel 25, and channel 26. According to the characteristics of the operation, loading channels of the queue are normally set to operate in pair, by alternating between 2 silos, due to maintenance and down time reasons. To say, channel 23 and channel 24 are served by cement from silo 2, while channel 25 and channel 26 are served by cement from silo 4; thus, the alternation between these two silos provides lead times for the system to stock sufficient amount of cement for each silo during down time to be able to continuously load cement to trucks without being interrupted by the lacking of cement, which disrupts the flow of the system.

The model starts operating when a unit of truck is submitted to QueueLine1 node, as seen in Figure 4-4. Firstly, the loading channels from silo 2, channel 23 and channel 24, are programmed to serve trucks while the loading channel from silo 4, channel 25 and channel 26, are switched off. If channel 23 and 24 are promptly available, the first truck in the line is randomly assigned to enter one of these channels. Each silo is estimated to serve 50 trucks per day, due to the amount of available cement produced and stored in the silo; therefore, the model switches from the upper circuit, in which channel 23 and channel 24 are contained, to the lower circuit, in which channel 25 and channel 26 are contained, when 50 trucks are served by the pair of channels on each day, as shown in Figure 3-38.. Similarly, the upper circuit is alternated to switch on when 50 trucks are loaded with cement from channel 25 and channel 26 combined.

According to the model, if a truck is assigned to load cement from channel 23, the truck will proceed from QueueLine1 node to LoadCement_23 Combi node.
Meanwhile, one unit of resource from SpaceOccupied, GenQ1, and Machine1 nodes are promptly sent to the LoadCement_23 node to begin the cement loading task from silo to the truck. When the task at the LoadCement23 node is complete, the truck proceeds to Loaded Queue node to signal that it is fully loaded with 30 tons of cement, while one unit of space is submitted to the Space_Available Queue node, allowing another truck to enter the site.

The Alternate1 Combi node turns on when the Loaded1 Queue node consolidates 50 trucks, which is simulated by the queue line 1 model, as illustrated in Figure 3-38. Hence, the Loaded1 Queue node, which receives one unit of resource per loaded truck, consolidates 50 trucks to switch the Alternate2 combi node on to shift the trucks waiting in the line to queue at the loading channels of an alternative silo.

On the other hand, the Alternate2 Combi node starts its task when the Loaded2 Queue node consolidates 50 trucks, which is simulated by the queue line 1 model, as seen in Figure 4-4. When the Loaded2 Queue node consolidates 50 trucks, the Alternate2 Combi node is switched on to shift the trucks waiting in the line back to queue at the loading channels of another silo.
If a truck is assigned to queue in the queue line 2, the possible loading channels that the truck can enter are channel 27, channel 28, channel 30, channel 31, and channel 32. Unlike queue line 1, where each silo consists of 2 loading channels, there are 3 loading channels per silo in queue line 2. Channel 27, channel 28, and channel 29 make up silo 6, while silo 8 consists of channel 30, channel 31, and channel 32. According to the characteristics of the operation, two of the five loading channels in this line rotationally operate at a time. Each channel of this silo is estimated to operate for cumulative 40 trucks and temporarily stop until 40 trucks are loaded by the preceding machine in cyclic manner, due to maintenance reason, while channel 29 is reserved as a spared channel to be used in emergency case, e.g. when one of the normally used loading machines is under maintenance.

The model is triggered to start when a unit of truck arrives at QueueLine2 node, as seen in Figure 4-5. Next, the truck is randomly assigned to one of the available loading channels in first-come-first-serve manner. At the beginning of the model, two channels are available for trucks to enter: channel 28 and channel 31. If a truck is assigned to load cement from channel 28, the truck will proceed from QueueLine2 node to LoadCement_28 Combi node. Meanwhile, one unit of resource from SpaceOccupied, Gen28, and Machine8 nodes are promptly sent to the LoadCement_28 node to begin the cement loading task from silo to the truck. When the task at the LoadCement_28 node is complete, the truck proceeds to Loaded Queue node to signal that it is fully loaded with 30 tons of cement, while one unit of space is released to the Space_Available Queue node, allowing another truck to enter the site. In addition, Loaded3_5 queue node, then, receives one unit resource from the completion of this task and withstands until 40 units are consolidated by this node. Hence, it transfers these 40 units of resources to
GenQ30, which triggers the operation of LoadCement_30 node, via Alternate7 and Buffer5 Combi nodes.

Hence, Loaded3_2 Queue node receives one unit resource from the completion of the task at LoadCement_31 node and withstands until 40 units are consolidated by this node. Hence, it transfers these 40 units of resources to GenQ4 and Gen32, respectively, which triggers the operation of LoadCement_32 node, via Alternate4 Combi node. Next, Loaded3_3 Queue node receives one unit resource from the completion of the task at LoadCement_32 node and withstands until 40 units are consolidated by this node. Hence, it transfers these 40 units of resources to Gen27, which triggers the operation of LoadCement_27 node. The cement loading system of the queue line 2 runs with 2 loading channels operating at a time, in cyclic manner.

The model starts with both GenQ3 and GenQ6 Queue nodes possessing initial contents of 40 in order to simulate the characteristics of the process that two of five loading channels of the line 2 are used at a time. In other words, the model starts with channel 28 and channel 31 operating, while channel 30 and channel 32 would turn on after 40 trucks are loaded by channel 28 and channel 31, respectively. Similarly, channel 27 stops operating after it serves 40 trucks during the cycle, and starts loading cement again when 40 trucks are loaded by channel 32. As a result, each channel of this silo would be closed after serving 40 trucks in the loop and return to operate again when 40 trucks are loaded by the preceding channel, which works consistently with the characteristics of the actual operation.
4.4 Simulation Results and Model Validation

Stroboscope and EZStrobe were used as simulation tools to predict the results for the cement loading process. As a general practice in simulation studies, simulation models need to be run with sufficiently high simulation time and the number of simulation cycles run needs to be adequately high in order to increase accuracy of predictions. Consequently, simulation time of 350 days, or 504,000 minutes, was assigned to the model to avoid effects from fluctuations at the beginning of the simulation. As a result, the total number of 50,985 trucks was simulated to load cement in this model.

4.4.1 Operation and Labor Costs

For the sake of obtaining the costs, relevant parameters were programmed based on the data given by the Asia Cement Plant, as shown in Figure 4-6. Each loading channel is operated by employing one operator to control the loading machine, while there are 2 operators working at weighbridge station at a time. Every operator is assigned to work for cumulative 8 hours per day, and promptly replaced by another operator when the duration is over. Operators at cement loading channels, weighbridges, and the front office are paid at $10 per 8-hour working period, which is a minimum wage for laborers in Thailand. As a result, total labor cost can be determined by using a formula shown in Equation 4-1.
\[ \text{TotLaborCost} = (\text{AveServer} + \text{Registrars} + \text{WB} \_ \text{operator}) \times \text{LaborCost} \times \frac{\text{SimTime}}{14.40} \quad \ldots (4-1) \]

where:

- \( \text{TotLaborCost} = \) total labor cost (\$)
- \( \text{AveServer} = \) the average number of loading channels operating at a time
- \( \text{Registrars} = \) the number of operators at the registration office
- \( \text{WB} \_ \text{operator} = \) the number of operators at the weighbridge station
- \( \text{LaborCost} = \) labor cost per operator per day (\$)
- \( \text{SimTime} = \) total simulation time (min)

To determine operation cost of the loading machines, electrical power of each loading machine, operation time, and electricity cost per kW-h unit need to be known. Average electricity cost during 2012 – 2013 in Thailand is 2.7 baht (\$0.09) per kW-h, which was applied to create a parameter (AveElectCost) to estimate electricity cost for the model, as seen in Figure 4-6. According to the data given by the plant, loading machines used in queue line 1 are different from the machines in queue line 2; thus, electrical energy consumed by loading machines in channel 23 – channel 26 varies from energy consumption of machines in channel 27 – channel 32. In other words, each loading machine in queue line 1 consumes 3.50 kW in an hour, while each loading machine in queue line 2 consumes 3.82 kW per hour. Electricity cost per hour of each loading machine in queue line 1 (ElectCost1) and queue line 2 (ElectCost2) were determined by multiplying kW-h of the machine by electricity price per unit, as seen in Figure 4-6. Hence, electricity cost of each loading machine can be calculated by multiplying the electricity cost per hour by total time that the machine operates during the simulation time. For example, an operation cost of a loading channel which locates in queue line 1 can be approximated by using a formula demonstrated by equation 4-2, while an operation
The cost of a channel which locates in queue line 2 can be approximated by using a formula demonstrated by equation 4-3.

\[
\text{Cost}_N = \text{LoadCement}_N \cdot \text{TotInst} \cdot \text{LoadCement}_N \cdot \text{AveDur} \times \text{ElectCost1} / 60 \quad \text{... (4-2)}
\]

\[
\text{Cost}_N = \text{LoadCement}_N \cdot \text{TotInst} \cdot \text{LoadCement}_N \cdot \text{AveDur} \times \text{ElectCost2} / 60 \quad \text{... (4-3)}
\]

where:

LoadCement\_N\_TotInst = the total number of trucks that have entered channel N
LoadCement\_N\_AveDur = the average loading time of truck in channel N (min)
ElectCost1 = electricity cost of the loading machine in queue line 1 ($/hour)
ElectCost2 = electricity cost of the loading machine in queue line 2 ($/hour)

Consequently, total operation cost created by all the loading machines in the system can be determined by summing up the operation cost of each machine, which is described by equation 4-4.

\[
\text{OperationCost} = \text{Cost}_23 + \text{Cost}_24 + \text{Cost}_25 + \text{Cost}_26 + \text{Cost}_27 \\
+ \text{Cost}_28 + \text{Cost}_30 + \text{Cost}_31 + \text{Cost}_32
\quad \text{... (4-4)}
\]
<table>
<thead>
<tr>
<th>LaborCost_8</th>
<th>Labor cost per 8 hours ($)</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>LaborCost</td>
<td>Labor cost per 24 hours ($)</td>
<td>LaborCost_8*3</td>
</tr>
<tr>
<td>Load</td>
<td>Load of cement per truck (tons)</td>
<td>30</td>
</tr>
<tr>
<td>AveServer</td>
<td>Average number of servers used</td>
<td>4</td>
</tr>
<tr>
<td>Registrars</td>
<td>Number of registrar</td>
<td>3</td>
</tr>
<tr>
<td>WB_operator</td>
<td>Number of operators at weighbridges</td>
<td>2</td>
</tr>
<tr>
<td>ElectCost1</td>
<td>Electricity Power of line 1 X time (kW-h) X cost per unit (dollars per hour)</td>
<td>3.50*(AveElectCost/Dollar_Baht)</td>
</tr>
<tr>
<td>ElectCost2</td>
<td>Electricity Power of line 2 X time (kW-h) X cost per unit (dollars per hour)</td>
<td>3.82*(AveElectCost/Dollar_Baht)</td>
</tr>
<tr>
<td>AveElectCost</td>
<td>Average electricity cost per kW-h (Baht)</td>
<td>2.7</td>
</tr>
<tr>
<td>Dollar_Baht</td>
<td>Currency exchange from Dollar to Baht</td>
<td>30</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost_27</td>
<td>Operation cost of server 27</td>
<td>LoadCement_27.TotInst<em>LoadCement_27.AveDur</em>ElectCost2/60</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>TotLaborCost</td>
<td>Total labor cost ($)</td>
<td>(AveServer+Registrars+WB_operator)<em>LaborCost</em>SimTime/1440</td>
</tr>
<tr>
<td>TotCost</td>
<td>Total related costs</td>
<td>OperationCost+TotLaborCost</td>
</tr>
</tbody>
</table>

Figure 4-6 Parameters used to calculate the results of the model
4.4.2 Program Coding

Since the objective of the study is to develop a model that minimizes truck waiting time with least machine idle time occurred in cement loading process, utilization factor formula, which is illustrated by equation 4-5, was established to indicate time utilization of the model.

\[
UtilizationFactor = \frac{(\text{Truck Total Time} - \text{Truck Waiting Time}) \times (\text{Machine Total Time} - \text{Machine Idle Time})}{(\text{Truck Total Time}) \times (\text{Machine Total Time})}
\]

… (4-5)

The utilization factor is a multiplication of two terms: proportion of truck productive time per throughput time and proportion of machine productive time per total operation time. The first term can be obtained by subtracting average truck waiting time at site from the average throughput time of trucks, and dividing by the throughput time. On the other hand, the second term can be carried out by subtracting machine idle time from total operation time of machines, and dividing by the total operation time. As a result, the possible range of the utilization factor varies from 0 to 1.

An ideal case is that when both truck waiting time and machine idle time are promptly equal to zero; thus, the utilization factor is maximized to reach a value of 1 under this circumstance. The maximization of the utilization factor in this ideal case means that the cement trucks can steadily flow without traffic and the amount of loading machines is adequately provided to fit the demand, without causing idle time.

Before the utilization factor can be determined, such results as average truck waiting time, average throughput time of truck, and average loading time of each
machine needs to be known. To do so, the formulae of these results were programmed via EZStrobe software, as shown in Figure 4-7.

Firstly, average truck waiting time (AveWaitTime) can be determined by combining waiting time at site, waiting time at the front office, waiting time at weighbridges, and waiting time at the waiting space together. The waiting time at site can be found by summing up total waiting time of all trucks that progressed to the queuing system, and dividing by the total number of trucks. Since the queuing system consists of 2 queues, average waiting time can be found by finding total waiting time of each queue separately, summing these two terms up, and dividing it by the total number of trucks from both queues, as illustrated by equation 4-6. The average truck waiting time at weighbridges can be found by summing the average waiting time at the inlet and outlet weighbridges, as seen in equation 4-7. Thus, the average truck waiting time can be determined by using equation 4-8.

\[
\text{AveWaitTime} = \text{AveWaitQ} + \text{TruckWait.AveWait} + \text{FrontOffice.AveWait} + \text{WeightWait}
\]

where:

\[
\text{AveWaitTime} = \text{average truck waiting time of the model (min)}
\]
\[
\text{AveWaitQ} = \text{average truck waiting at the cement loading site (min)}
\]
\[
\text{TruckWait.AveWait} = \text{average truck waiting time at the waiting space (min)}
\]
\[
\text{FrontOffice.AveWait} = \text{average truck waiting at the front office (min)}
\]
\[
\text{Weightwait.AveWait} = \text{average truck waiting at the inlet weighbridge (min)}
\]
\[
\text{OutQueue.AveWait} = \text{average truck waiting at the outlet weighbridge (min)}
\]
\[
\text{QueueLine1.AveWait} = \text{average waiting time for trucks entered queue 1 (min)}
\]
\[
\text{QueueLine2.AveWait} = \text{average waiting time for trucks entered queue 2 (min)}
\]
\[
\text{QueueLine1.TotCount} = \text{the total amount of trucks that entered queue 1}
\]
\[
\text{QueueLine2.TotCount} = \text{the total amount of trucks that entered queue 2}
\]
Secondly, average loading time (AveLoadingTime) can be determined in a similar way to the calculation of truck waiting time. To say, average loading time of each channel is multiplied by the total amount of trucks that has entered the channel to yield total loading time that the channel has operated. Next, total loading time of all loading channels are combined and divided by the total amount of trucks from all channels, as represented by equation 4-9.

\[ Ave\text{LoadingTime} = \frac{(\text{LoadCement}_23.\text{AveDur} \times \text{LoadCement}_23.\text{TotInst} + \text{LoadCement}_24.\text{AveDur} \times \text{LoadCement}_24.\text{TotInst} + \text{LoadCement}_25.\text{AveDur} \times \text{LoadCement}_25.\text{TotInst} + \text{LoadCement}_26.\text{AveDur} \times \text{LoadCement}_26.\text{TotInst} + \text{LoadCement}_27.\text{AveDur} \times \text{LoadCement}_27.\text{TotInst} + \text{LoadCement}_28.\text{AveDur} \times \text{LoadCement}_28.\text{TotInst} + \text{LoadCement}_29.\text{AveDur} \times \text{LoadCement}_29.\text{TotInst} + \text{LoadCement}_30.\text{AveDur} \times \text{LoadCement}_30.\text{TotInst} + \text{LoadCement}_31.\text{AveDur} \times \text{LoadCement}_31.\text{TotInst} + \text{LoadCement}_32.\text{AveDur} \times \text{LoadCement}_32.\text{TotInst})}{(\text{LoadCement}_23.\text{TotInst} + \text{LoadCement}_24.\text{TotInst} + \text{LoadCement}_25.\text{TotInst} + \text{LoadCement}_26.\text{TotInst} + \text{LoadCement}_27.\text{TotInst} + \text{LoadCement}_28.\text{TotInst} + \text{LoadCement}_29.\text{TotInst} + \text{LoadCement}_30.\text{TotInst} + \text{LoadCement}_31.\text{TotInst} + \text{LoadCement}_32.\text{TotInst})} \ldots (4-9) \]

where:

AveLoadingTime = average loading time of trucks in the model (min)
LoadCement_N.TotInst = the total number of trucks that have entered channel N
LoadCement_N.AveDur = the average loading time of trucks in channel N (min)

Next, average throughput time of trucks (AveTotalTime) needs to be known. To do so, average loading time, average waiting time, and average duration of each task in the process are added up. The throughput time formula is illustrated by equation 4-10.

where:

\text{AveTotalTime} = \text{average throughput time of trucks in the model (min)}
\text{FrontOffice.AveWait} = \text{average waiting time of trucks at waiting space (min)}
\text{TruckRegister.AveDur} = \text{the average registration time of trucks (min)}
\text{TruckProceed.AveDur} = \text{the average travel from front office to weighbridge (min)}
\text{TruckWait.AveWait} = \text{the average waiting time at the inlet weighbridge (min)}
\text{MeasureWeight1.AveDur} = \text{the average processing time at the inlet weighbridge (min)}
\text{MeasureWeight2.AveDur} = \text{the average processing time at the outlet weighbridge (min)}
\text{TruckTravel_In.AveDur} = \text{the average travel time from weighbridge to site (min)}
\text{TruckTravel_Out.AveDur} = \text{the average travel time from a channel to weighbridge (min)}
\text{Sealing.AveDur} = \text{the average sealing time of trucks (min)}
\text{LoadCement_N.AveDur} = \text{the average loading time of trucks in channel N (min)}
\text{LoadCement_N.TotInst} = \text{the total number of trucks that have entered channel N (min)}
\text{QueueLine1.AveWait} = \text{average waiting time for trucks entered queue 1 (min)}
\text{QueueLine2.AveWait} = \text{average waiting time for trucks entered queue 2 (min)}
\text{QueueLine1.TotCount} = \text{the total amount of trucks that entered queue 1 (min)}
\text{QueueLine2.TotCount} = \text{the total amount of trucks that entered queue 2 (min)}
In addition, interarrival time of trucks entering the system (Interarrival) and production rate (ProdRate) can be obtained by using formulae in equation 4-11 and equation 4-12, respectively.

\[ \text{Interarrival} = \text{ArrivalRecord.AveInter} \quad \ldots \ (4-11) \]

\[ \text{ProdRate} = \text{Count.TotInst} \times \frac{\text{Load}}{\text{SimTime}} \quad \ldots \ (4-12) \]

where:

Interarrival = interarrival time of trucks arrived at the plant (min)
ProdRate = production rate of the cement loading process (tons per minute)
ArrivalRecord.AveInter = average time between truck arrivals (min)
Count.TotInst = the total number of trucks that have quit the process
SimTime = total simulation time (min)

|--------------|--------------------------------|----------------------------------------------------------------------------------------------------------------------------------|

<table>
<thead>
<tr>
<th>Interarrival</th>
<th>Interarrival time</th>
<th>ArrivalRecord.AveInter</th>
</tr>
</thead>
<tbody>
<tr>
<td>ProdRate</td>
<td>Production Rate (tons per minute)</td>
<td>Count.TotInst*Load/SimTime</td>
</tr>
</tbody>
</table>

**Figure 4-7 Program codes to obtain time results of the model**
Furthermore, total machine idle time and total operation time of loading machines need to be known for the sake of determining the utilization proportion for the loading channels, as illustrated in Figure 4-8. To begin with, total input time of loading machines can be found by combining total operating time of machines in each queue line together. There are two from possible four loading machines operating at a time in queue line 1, while two from possible three loading machines from silo 6 are rotationally set to operate, with additional 2 machines from silo 8 assigned to serve for 8 hours per day. The total input time of machines (TotInputTime) can be determined by using a formula shown in equation 4-13 while the total productive time of loading machines (MCU_Time) can be determined by using equation 4-14.

\[
\text{TotInputTime} = (4 \times \frac{\text{SimTime}}{2}) + (3 \times \frac{\text{SimTime}}{2} \times \frac{2}{3}) + (2 \times \frac{\text{SimTime}}{3}) \quad \text{... (4-13)}
\]

\[
\text{MCU\_Time} = (\text{LoadCement\_23.AveDur} \times \text{LoadCement\_23.TotInst} \\
+ \text{LoadCement\_24.AveDur} \times \text{LoadCement\_24.TotInst} \\
+ \text{LoadCement\_25.AveDur} \times \text{LoadCement\_25.TotInst} \\
+ \text{LoadCement\_26.AveDur} \times \text{LoadCement\_26.TotInst} \\
+ \text{LoadCement\_27.AveDur} \times \text{LoadCement\_27.TotInst} \\
+ \text{LoadCement\_28.AveDur} \times \text{LoadCement\_28.TotInst} \\
+ \text{LoadCement\_29.AveDur} \times \text{LoadCement\_29.TotInst} \\
+ \text{LoadCement\_30.AveDur} \times \text{LoadCement\_30.TotInst} \\
+ \text{LoadCement\_31.AveDur} \times \text{LoadCement\_31.TotInst} \\
+ \text{LoadCement\_32.AveDur} \times \text{LoadCement\_32.TotInst}) \\
\quad \text{... (4-14)}
\]

where:

\[
\text{TotInputTime} = \text{total input time of loading machines used in the model (min)} \\
\text{MCU\_Time} = \text{total productive time of loading machines used in the model (min)} \\
\text{LoadCement\_N.TotInst} = \text{the total number of trucks that have entered channel N} \\
\text{LoadCement\_N.AveDur} = \text{the average loading time of trucks in channel N (min)} \\
\text{SimTime} = \text{total simulation time (min)}
\]
Next, total idle time of all loading machines needs to be determined. The total machine idle time (TotIdleTime) can be found by subtracting the machine productive time (MCU_Time) from the total machine input time (TotInputTime), as described by equation 4-15.

\[ \text{TotIdleTime} = \text{TotInputTime} - \text{MCU\_Time} \] \hspace{5cm} (4-15)

Finally, utilization factor between percent productive time of trucks and machines, as illustrated by equation 3-29, can be determined by multiplying two terms: percent utilization of machine (MC\_UtiRate) and percent of truck productive time (TruckProdTime), which are shown by equation 4-16 and 4-17, respectively. Therefore, the utilization factor can be found by using equation 4-18.

\[ \text{MC\_UtiRate} = \frac{\text{TotInputTime} - \text{TotIdleTime}}{\text{TotInputTime}} \] \hspace{5cm} (4-16)

\[ \text{TruckProdTime} = \frac{\text{AveTotalTime} - \text{AveWaitTime}}{\text{AveTotalTime}} \] \hspace{5cm} (4-17)

\[ \text{Utilization} = \text{MC\_UtiRate} \times \text{TruckProdTime} \] \hspace{5cm} (4-18)

| Machine productive time | MCU\_Time | \( \text{LoadCement}_23 \times \text{TotInst} \times \text{LoadCement}_23 \times \text{AveDur} + \text{LoadCement}_24 \times \text{TotInst} \times \text{LoadCement}_24 \times \text{AveDur} + \text{LoadCement}_25 \times \text{TotInst} \times \text{LoadCement}_25 \times \text{AveDur} + \text{LoadCement}_26 \times \text{TotInst} \times \text{LoadCement}_26 \times \text{AveDur} + \text{LoadCement}_27 \times \text{TotInst} \times \text{LoadCement}_27 \times \text{AveDur} + \text{LoadCement}_28 \times \text{TotInst} \times \text{LoadCement}_28 \times \text{AveDur} + \text{LoadCement}_29 \times \text{TotInst} \times \text{LoadCement}_29 \times \text{AveDur} + \text{LoadCement}_30 \times \text{TotInst} \times \text{LoadCement}_30 \times \text{AveDur} + \text{LoadCement}_31 \times \text{TotInst} \times \text{LoadCement}_31 \times \text{AveDur} + \text{LoadCement}_32 \times \text{TotInst} \times \text{LoadCement}_32 \times \text{AveDur} \) |
| TotInputTime | Total input time of machines | \( 4 \times \text{SimTime} \) |
| MC\_UtiRate | Percent Utilization rate of machines (%) | \( \frac{\text{TotInputTime} - \text{TotIdleTime}}{\text{TotInputTime}} \) |
| TotIdleTime | Total idle time | \( \text{TotInputTime} - \text{MCU\_Time} \) |
| TruckProdTime | Percent of truck productive time | \( \frac{\text{AveTotalTime} - \text{AveWaitTime}}{\text{AveTotalTime}} \) |
| Utilization | Utilization between percent productive time of trucks and machines | \( \text{MC\_UtiRate} \times \text{TruckProdTime} \) |

Figure 4-8 Program codes to determine utilization results of the model
4.4.3 Simulation Results

Simulation time of 504,000 minutes, or 350 days, was assigned to the model to avoid effects from fluctuations at the beginning of the simulation. As a result, the total number of 50,985 trucks was simulated to load cement in this model.

The results from Stroboscope, as illustrated in Table 4-1, show that the average duration that a truck spends in the system is 68.41 minutes. The average time that a truck spends waiting in the queue at the cement loading site turns out to be 27.46 minutes, from the average total waiting time in all queues of 27.83 minutes per truck. To say, 98.7% of the truck waiting time in the model is the waiting time at the site. As a result, the productive time of truck, which is defined by subtracting total waiting time from the throughput time, is 59.3%. In addition, average loading time per truck is found to be 23.57 minutes per truck. Furthermore, interarrival time of trucks turns out to be 9.88 minutes per arrival, which means that the truck arrival rate is, on average, 146 arrivals per day.

The results also show that the total input time of all machines is 2.016 million minutes during the simulation time, while the total idle time of loading machines turns out to be 814,008 minutes. The idle time contributes to 40.4% of the total machine operating time; thus, the productive time of the machines is 59.6%. According to the simulation, the total related cost turns out to be 101,186 dollars, which can be categorized into 6,685.4 dollars from electricity cost and 94,500.3 dollars from labor cost, as illustrated in Table 4-2. In addition, the system is found to load 3.04 tons of cement to trucks per minutes.

Since the percent utilization of trucks and loading machines are 0.593 and 0.596, respectively, the utilization factor of the model, which is a multiplication of these values, turns to be 0.354, as illustrated in Table 4-3.
### Table 4-1 Prediction of the durations from the simulation model of the default system

<table>
<thead>
<tr>
<th>Duration</th>
<th>Minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interarrival time</td>
<td>9.88054</td>
</tr>
<tr>
<td>Average loading time</td>
<td>23.5663</td>
</tr>
<tr>
<td>Average total time of trucks</td>
<td>68.4129</td>
</tr>
<tr>
<td>Average truck waiting time at site</td>
<td>27.4643</td>
</tr>
<tr>
<td>Average truck waiting time at all queues</td>
<td>27.8276</td>
</tr>
<tr>
<td>Total input time of machines</td>
<td>2,016,010</td>
</tr>
<tr>
<td>Machine productive time</td>
<td>1,202,000</td>
</tr>
<tr>
<td>Total idle time</td>
<td>814,008</td>
</tr>
</tbody>
</table>

### Table 4-2 Prediction of costs from the simulation model of the default system

<table>
<thead>
<tr>
<th>Cost</th>
<th>Dollars</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity Cost of line 1 (dollars per hour)</td>
<td>0.315</td>
</tr>
<tr>
<td>Electricity Cost of line 2 (dollars per hour)</td>
<td>0.3438</td>
</tr>
<tr>
<td>Operation cost of server 23</td>
<td>633.442</td>
</tr>
<tr>
<td>Operation cost of server 24</td>
<td>376.814</td>
</tr>
<tr>
<td>Operation cost of server 25</td>
<td>721.154</td>
</tr>
<tr>
<td>Operation cost of server 26</td>
<td>478.657</td>
</tr>
<tr>
<td>Operation cost of server 27</td>
<td>1,003.35</td>
</tr>
<tr>
<td>Operation cost of server 28</td>
<td>990.391</td>
</tr>
<tr>
<td>Operation cost of server 30</td>
<td>795.768</td>
</tr>
<tr>
<td>Operation cost of server 31</td>
<td>880.789</td>
</tr>
<tr>
<td>Operation cost of server 32</td>
<td>805.025</td>
</tr>
<tr>
<td>Total labor cost ($)</td>
<td>94,500.3</td>
</tr>
<tr>
<td>Total operation cost ($)</td>
<td>6,685.39</td>
</tr>
<tr>
<td>Total related costs ($)</td>
<td>101,186</td>
</tr>
</tbody>
</table>

### Table 4-3 Indicators results of the simulation model of the default system

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent of truck productive time (%)</td>
<td>0.593241</td>
</tr>
<tr>
<td>Percent Utilization rate of machines (%)</td>
<td>0.596228</td>
</tr>
<tr>
<td>Utilization between percent productive time of trucks and machines</td>
<td>0.353707</td>
</tr>
</tbody>
</table>
The results also show that there are, on average, 6.92 trucks dwelling in the cement loading system at a time. Furthermore, the maximum number of trucks presenting in the system is 30 trucks at a time, as seen in Figure 4-9, which indicates that the parking space of 40 trucks at the queues in the loading site has never been fully occupied during the simulation time. Also, the production rate of the system seems to be steady, as shown in Figure 4-10. Thus, it can be implied that the current system has adequate capacity to handle the flow of cement trucks.

Figure 4-9: Graph shows amount of trucks in the system over time for default model

Obviously, it is found that the amount of trucks dwelling in the system during the day seems to dramatically increase from 1.00 PM to reach its peak at 4.30 PM – 6.30 PM, and declines gradually to reach the average number of 6 – 7 trucks at around 10.00 PM, as illustrated in Figure 4-11.
Figure 4-10 Graph shows the cumulative number of trucks complete the process over time

Figure 4-11 Graph shows the amount of trucks in the system during 24-hour period
Furthermore, it is observed from the results that the average number of trucks waiting in the queues at the loading site is 2.78 trucks during the simulation time. To be specific, the queue line 1 contains, on average, 0.18 trucks waiting in the line, while the average number of trucks waiting in queue line 2 is 2.60 trucks. The finding indicates that an unbalance exists in the queuing system of the current cement loading process practice. Evidences of the unbalanced queuing system are illustrated in Figure 4-12 and Figure 4-13, which are charts that show the amount of trucks queuing in the queue line 1 and queue line 2 over time, respectively.

![Number of Trucks Waiting in Queue Line 1](image)

**Figure 4-12 Chart shows the number of trucks in queue line 1 over time**
Figure 4-13 Chart shows the number of trucks in queue line 2 over time

4.4.4 Model Validation

Model validation was conducted to measure how accurate that the cement loading process can be predicted by the simulation model. The model was evaluated in their ability to predict the average truck waiting time, average loading time, and average throughput time of trucks. In addition, other related parameters, such as interarrival time during each period, truck travel times, and average truck arrival rate, are investigated. The simulation model is shown to predict truck waiting time, loading time, throughput time, and the other related parameters with reasonable accuracy, as seen in Table 4-4.
### Table 4-4 Validation of the simulation model of the default system

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Actual Result</th>
<th>Model Result</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Truck Waiting Time at Site</td>
<td>25.96 min</td>
<td>27.46 min</td>
<td>+5.78%</td>
</tr>
<tr>
<td>Average Loading Time</td>
<td>23.97 min</td>
<td>23.57 min</td>
<td>-1.67%</td>
</tr>
<tr>
<td>Average Total Time of Trucks</td>
<td>71.54 min</td>
<td>68.41 min</td>
<td>-4.38%</td>
</tr>
<tr>
<td>Average Loading Time of Channel 23</td>
<td>19.41 min</td>
<td>18.94 min</td>
<td>-2.42%</td>
</tr>
<tr>
<td>Average Loading Time of Channel 24</td>
<td>18.84 min</td>
<td>18.74 min</td>
<td>-0.53%</td>
</tr>
<tr>
<td>Average Loading Time of Channel 25</td>
<td>22.54 min</td>
<td>22.50 min</td>
<td>-0.18%</td>
</tr>
<tr>
<td>Average Loading Time of Channel 26</td>
<td>22.47 min</td>
<td>22.53 min</td>
<td>+0.22%</td>
</tr>
<tr>
<td>Average Loading Time of Channel 27</td>
<td>28.61 min</td>
<td>28.61 min</td>
<td>-</td>
</tr>
<tr>
<td>Average Loading Time of Channel 28</td>
<td>28.05 min</td>
<td>28.13 min</td>
<td>+0.29%</td>
</tr>
<tr>
<td>Average Loading Time of Channel 30</td>
<td>22.78 min</td>
<td>22.69 min</td>
<td>-0.40%</td>
</tr>
<tr>
<td>Average Loading Time of Channel 31</td>
<td>25.58 min</td>
<td>24.99 min</td>
<td>-2.31%</td>
</tr>
<tr>
<td>Average Loading Time of Channel 32</td>
<td>22.90 min</td>
<td>22.96 min</td>
<td>+0.26%</td>
</tr>
<tr>
<td>Average Registration Time</td>
<td>8.96 min</td>
<td>8.97 min</td>
<td>+0.11%</td>
</tr>
<tr>
<td>Average Truck Travel Time to Inlet Weighbridge</td>
<td>3.79 min</td>
<td>3.79 min</td>
<td>-</td>
</tr>
<tr>
<td>Average Time at Inlet Weighbridge</td>
<td>0.34 min</td>
<td>0.33 min</td>
<td>-2.94%</td>
</tr>
<tr>
<td>Average Truck Travel Time to the Site</td>
<td>1.46 min</td>
<td>1.45 min</td>
<td>-0.68%</td>
</tr>
<tr>
<td>Average Sealing Time</td>
<td>1.42 min</td>
<td>1.43 min</td>
<td>+0.70%</td>
</tr>
<tr>
<td>Average Truck Travel Time to Outlet Weighbridge</td>
<td>0.71 min</td>
<td>0.71 min</td>
<td>-</td>
</tr>
<tr>
<td>Average Time at Outlet Weighbridge</td>
<td>0.33 min</td>
<td>0.33 min</td>
<td>-</td>
</tr>
<tr>
<td>All-Day Interarrival Time</td>
<td>9.71 min</td>
<td>9.88 min</td>
<td>+1.75%</td>
</tr>
<tr>
<td>Off-Peak Interarrival Time</td>
<td>16.84 min</td>
<td>16.87 min</td>
<td>+0.18%</td>
</tr>
<tr>
<td>AM Mid-Peak Interarrival Time</td>
<td>11.18 min</td>
<td>11.18 min</td>
<td>-</td>
</tr>
<tr>
<td>Peak Interarrival Time</td>
<td>5.93 min</td>
<td>5.93 min</td>
<td>-</td>
</tr>
<tr>
<td>PM Mid-Peak Interarrival Time</td>
<td>9.32 min</td>
<td>9.22 min</td>
<td>-1.07%</td>
</tr>
<tr>
<td>1-Day Loop</td>
<td>1,440 min</td>
<td>1,382.5 min</td>
<td>-3.99%</td>
</tr>
<tr>
<td>Average Truck Arrival Rate per Day</td>
<td>148 trucks</td>
<td>140 trucks</td>
<td>-5.71%</td>
</tr>
</tbody>
</table>
Chapter 5
IMPROVEMENT MODELS FOR THE CEMENT LOADING PROCESS
WITH RESULTS AND SENSITIVITY ANALYSES

5.1 Model Improvement

In this chapter, various simulation models are presented and compared in terms of effectiveness to improve the utilization factor by reducing truck waiting time and idle time of the channels. Prior to making improvements on the default model in chapter 3, flaws need to be known for the sake of making improvement on the correct points. So far, two flaws have been observed from the results of the simulation model of the current cement loading process practice.

Firstly, an unbalance occurs in the queuing system of the current cement loading process. To say, the average number of trucks queuing in the line 2 is greater than the average number of trucks waiting in the line 1. Such evidences of the unbalanced queuing system are illustrated in Figure 4-12 and Figure 4-13. Consequently, either line balancing or merging queue needs to be applied to the queuing system in order to balance the waiting times and the lengths of trucks waiting in these queues. The study opted to improve the model by merging queue line 1 and queue line 2 together, rather than performing line balancing, since the two queue lines are located on the same plane and adjacent to each other, which supports this idea.

Secondly, the number of trucks presenting in the system is high during the peak and the PM mid-peak periods, as a result of high arrival rate, as seen in Figure 4-11. Therefore, additional loading channels should be added to the model
during these periods for the sake of reducing the queue length by increasing the capacity of the system at the bottleneck task.

5.1.1 Cement Loading Process Model of the Merged-Queue System

An Improvement was made on the simulation model of the default cement loading process by merging 2 waiting line of trucks at the site together. To do so, the QueueLine1 node and the QueueLine2 node, as seen in Figure 4-4 and 4-5, respectively, are merged into one queue node. The merged queue node is represented by QueueLine node, as illustrated in Figure 5-1. However, the rest of the whole model is the same as the default simulation model, as seen in Figure 5-3.

According to the model of the merged queue cement loading process, when a truck arrives at the Enter Combi node, with a space unit submitted from Call Queue node, the truck will proceed to the single queue line by dwelling at the QueueLine node, as seen in Figure 5-1 and 5-2. Next, the truck enters the cement loading channel by progressing to one of the available LoadCement Combi nodes in first-come-first-serve manner. For instance, if channel 23 is unoccupied by the time a truck is at the pole position in the line, it would be assigned to enter the LoadCement_23 node. However, if there are more than one loading channel available, the truck would be assigned to one of those available channels in random manner. When the truck is simulated to be fully loaded with a bulk of 30 tons of cement, it proceeds to Loaded Queue node and enters Sealing node, as seen in Figure 5-3.
Figure 5-1 Cement loading system of the merged queue model from EZStrobe
Figure 5-2 Cement loading system of the merged queue model from EZStrobe (continued)
Figure 5-3 Cement loading system of the merged queue model from EZStrobe (continued)
The simulation model of the merged-queue cement loading process was run for 504,000 minutes, as used in the default model. The results from Stroboscope show that the simulation model yields an average throughput time of 47.69 minutes per truck, which is 23.85 minutes less that the average actual throughput time of the default process. In other words, the throughput time of trucks after merging queues is reduced by 33.33%, or one third of the actual throughput time. Furthermore, the average truck waiting time at the loading queue turns to be 6.98 minutes per truck, which is 17.98 minutes less than the actual average truck waiting time at the loading queue. In other words, the truck waiting time at the loading queue is reduced by 73.11%, compared to the actual waiting time of the default process. Besides, the average overall truck waiting time of the model turns to be 7.32 minutes per truck, corresponding to 15.4% of the average throughput time of the model, while the average overall truck waiting time of the default model is corresponding to 40.7% of its throughput time.

In addition, average loading time per truck is found to be 23.34 minutes per truck and interarrival time of trucks turns to be 9.86 minutes per arrival, which are close to those results from the default model.

The results also show that the total input time of all machines is 2.016 million minutes during the simulation time, while the total idle time of loading machines turns out to be 823,086 minutes. The idle time contributes to 40.8% of the total machine operating time; thus, the productive time of the machines is 59.2%, which is close to the productive time of 59.6% from the default model. In addition, the total related cost turns out to be 101,110 dollars, which can be categorized into 6,610.1 dollars from electricity cost and 94,500.2 dollars from labor cost. The system is also found to have the same production rate as the default model since the production rate turns to be at 3.04 tons per minutes.
Since the percent utilization of trucks and loading machines are 0.846 and 0.596, respectively, the utilization factor of the model, which is a multiplication of these values, turns out to be 0.501. The utilization factor of the merged-queue cement loading process model is found to increase by 0.1471, or 41.6%, compared to the result from the default cement loading process model.

Table 5-1 Prediction of the durations from the simulation model after merging queues

<table>
<thead>
<tr>
<th>Durations</th>
<th>Default Model (min)</th>
<th>Merged-Queue Model (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interarrival time</td>
<td>9.88054</td>
<td>9.86203</td>
</tr>
<tr>
<td>Average loading time</td>
<td>23.5663</td>
<td>23.3443</td>
</tr>
<tr>
<td>Average total time of trucks</td>
<td>68.4129</td>
<td>47.6884</td>
</tr>
<tr>
<td>Average truck waiting time at site</td>
<td>27.4643</td>
<td>6.97625</td>
</tr>
<tr>
<td>Average truck waiting time at all queues</td>
<td>27.8276</td>
<td>7.32415</td>
</tr>
<tr>
<td>Total input time of machines</td>
<td>2,016,010</td>
<td>2,016,010</td>
</tr>
<tr>
<td>Machine productive time</td>
<td>1,202,000</td>
<td>1,192,290</td>
</tr>
<tr>
<td>Total idle time</td>
<td>814,008</td>
<td>823,086</td>
</tr>
</tbody>
</table>

Table 5-2 Prediction of costs from the simulation model after merging queues

<table>
<thead>
<tr>
<th>Costs</th>
<th>Default Model ($)</th>
<th>Merged-Queue Model ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity Cost of line 1 (dollars per hour)</td>
<td>0.315</td>
<td>0.315</td>
</tr>
<tr>
<td>Electricity Cost of line 2 (dollars per hour)</td>
<td>0.3438</td>
<td>0.3438</td>
</tr>
<tr>
<td>Operation cost of server 23</td>
<td>633.442</td>
<td>642.112</td>
</tr>
<tr>
<td>Operation cost of server 24</td>
<td>376.814</td>
<td>484.114</td>
</tr>
<tr>
<td>Operation cost of server 25</td>
<td>721.154</td>
<td>749.71</td>
</tr>
<tr>
<td>Operation cost of server 26</td>
<td>478.657</td>
<td>588.82</td>
</tr>
<tr>
<td>Operation cost of server 27</td>
<td>1,003.35</td>
<td>588.82</td>
</tr>
<tr>
<td>Operation cost of server 28</td>
<td>990.391</td>
<td>912.515</td>
</tr>
<tr>
<td>Operation cost of server 30</td>
<td>795.768</td>
<td>742.855</td>
</tr>
<tr>
<td>Operation cost of server 31</td>
<td>880.789</td>
<td>817.318</td>
</tr>
<tr>
<td>Operation cost of server 32</td>
<td>805.025</td>
<td>742.914</td>
</tr>
<tr>
<td>Total labor cost ($)</td>
<td>94,500.3</td>
<td>94,500.2</td>
</tr>
<tr>
<td>Total operation cost ($)</td>
<td>6,685.39</td>
<td>6,610.07</td>
</tr>
<tr>
<td>Total related costs ($)</td>
<td>101,186</td>
<td>101,110</td>
</tr>
</tbody>
</table>
Table 5-3 Indicators results of the simulation model after merging queues

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Default Model</th>
<th>Merged-Queue Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent of truck productive time (%)</td>
<td>0.593241</td>
<td>0.846417</td>
</tr>
<tr>
<td>Percent Utilization rate of machines (%)</td>
<td>0.596228</td>
<td>0.591724</td>
</tr>
<tr>
<td>Utilization between percent productive time of trucks and machines</td>
<td>0.353707</td>
<td>0.500845</td>
</tr>
</tbody>
</table>

Figure 5-4 Graph shows amount of trucks in the system over time after merging queues

The average number of trucks dwelling in the system decreases from 6.92 trucks to 4.84 trucks, after queues were merged, or decrease by 30.06%. Furthermore, the maximum number of trucks presenting in the system is 24 trucks at a time, as seen in Figure 5-4. Again, it indicates that the parking space of 40 trucks at the queues in the loading site has never been fully occupied during the 350-day simulation time. Also, it can be implied that the current system has
adequate capacity to handle the flow of cement trucks since the production rate of the system, as shown in Figure 5-5, is quite steady.

Obviously, it is found that the amount of trucks dwelling in the system during a day seems to dramatically increase from 1.00 PM to reach its peak at 3.00 PM – 4.30 PM, and gradually declines to reach the peak shoulder at around 6.00 PM, as illustrated in Figure 5-6.

Moreover, it can be observed from the results that the average number of trucks waiting in the merged loading queue at the site is 0.71 trucks during the simulation time, compared to 2.78 trucks in the default model, as shown in Figure 4-7. The finding also indicates that after the two queues were merged, the average number of trucks waiting in the queue decreases by 2.07 trucks, or 74.5%.

Figure 5-5 Graph shows the cumulative number of trucks complete the process over time
Figure 5-6 Graph shows the amount of trucks in the system during 24-hour period

Figure 5-7 Chart shows the number of trucks in the loading queue over time
5.2 Results and Sensitivity Analysis of the Merged-Queue Cement Loading Process Models with Adjustments on the Number of Cement Loading Channels

According to the simulation results in the previous section, percent of truck productive time was improved from 0.653 to 0.846 after two loading queues were merged, sending an impact to increase the utilization factor from 0.354 to 0.501. In addition, throughput time of trucks and truck waiting time were dramatically reduced from 71.5 minutes and 26 minutes to 7 minutes and 47.7 minutes, respectively. However, the percent utilization of machines, which indicates the productive time of loading machines, still unchanged after the queues were merged. Consequently, various set of cement loading channels were applied to the merged-queue cement loading system model in the previous section to compare the results in terms of utilization factor, percent of truck productive time, percent utilization of machines, and total related cost.

Table 5-4 Sensitivity analysis on the cement loading process models with various set of cement loading channels

<table>
<thead>
<tr>
<th>Number of Machines</th>
<th>Utilization Factor</th>
<th>% Truck Utility</th>
<th>% Machine Utility</th>
<th>Total Related Cost ($)</th>
<th>Waiting Time at site (min)</th>
<th>Total Waiting Time (min)</th>
<th>Total Time of Truck (min)</th>
<th>Loading Time (min)</th>
<th>Avg. Queue Length (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.00028</td>
<td>0.00028</td>
<td>0.99992</td>
<td>65,793</td>
<td>902.44</td>
<td>145,192</td>
<td>145,233</td>
<td>23.35</td>
<td>38.72</td>
</tr>
<tr>
<td>2</td>
<td>0.00115</td>
<td>0.00116</td>
<td>0.98962</td>
<td>78,997</td>
<td>428.23</td>
<td>34,208</td>
<td>34,248</td>
<td>22.67</td>
<td>37.41</td>
</tr>
<tr>
<td>3</td>
<td>0.38231</td>
<td>0.48583</td>
<td>0.78691</td>
<td>90,597</td>
<td>42.22</td>
<td>42.59</td>
<td>82.83</td>
<td>22.67</td>
<td>37.41</td>
</tr>
<tr>
<td>4</td>
<td>0.50085</td>
<td>0.84642</td>
<td>0.59172</td>
<td>101,110</td>
<td>6.98</td>
<td>7.32</td>
<td>47.69</td>
<td>23.34</td>
<td>4.29</td>
</tr>
<tr>
<td>5</td>
<td>0.40965</td>
<td>0.96846</td>
<td>0.42299</td>
<td>110,765</td>
<td>0.87</td>
<td>1.23</td>
<td>39.09</td>
<td>20.85</td>
<td>0.09</td>
</tr>
<tr>
<td>6</td>
<td>0.35675</td>
<td>0.98497</td>
<td>0.36219</td>
<td>121,553</td>
<td>0.24</td>
<td>0.59</td>
<td>39.05</td>
<td>21.45</td>
<td>0.02</td>
</tr>
<tr>
<td>7</td>
<td>0.31970</td>
<td>0.9932</td>
<td>0.32316</td>
<td>132,394</td>
<td>0.07</td>
<td>0.42</td>
<td>39.77</td>
<td>22.34</td>
<td>0.01</td>
</tr>
<tr>
<td>8</td>
<td>0.30143</td>
<td>0.99046</td>
<td>0.30433</td>
<td>143,445</td>
<td>0.02</td>
<td>0.40</td>
<td>41.40</td>
<td>23.99</td>
<td>0.00</td>
</tr>
<tr>
<td>9</td>
<td>0.28125</td>
<td>0.99134</td>
<td>0.28371</td>
<td>154,322</td>
<td>0.01</td>
<td>0.37</td>
<td>42.61</td>
<td>25.24</td>
<td>0.00</td>
</tr>
<tr>
<td>Default (4)</td>
<td>0.35371</td>
<td>0.59324</td>
<td>0.59623</td>
<td>101,186</td>
<td>27.46</td>
<td>27.83</td>
<td>68.41</td>
<td>23.57</td>
<td>1.63</td>
</tr>
<tr>
<td>Merged Queue</td>
<td>0.50085</td>
<td>0.84642</td>
<td>0.59172</td>
<td>101,110</td>
<td>6.98</td>
<td>7.32</td>
<td>47.69</td>
<td>23.34</td>
<td>0.71</td>
</tr>
</tbody>
</table>
The sensitivity analysis results on the cement loading process model indicate that the default simulation model with merged loading queue, operating by using 4 loading channels at a time, yields the greatest utilization factor value among the simulation models, as seen in Table 5-4. The second greatest utilization factor is obtained by the simulation model with 5 loading machines, yielding utilization factor of 0.410. The utilization factor trend of the models is shown in Figure 5-8. Obviously, the percent of truck productive time tends to increase with the higher number of loading machines operated. Similarly, the total related cost tends to harmoniously increase with the greater number of machines. However, the percent utilization of machines seems to decrease when more machines are operated in the system. The reason why the percent utilization of machines declines in opposite direction to the percent of truck productive time is that, even though the demand during peak period tends to be better served by the improved capacity, the additional loading machines creates more idle time as a shadow. Such evidences of the improved truck flow is shown by waiting time at site, total waiting time, total time of truck, and average queue length, as illustrated in Table 5-4.

Furthermore, it can be inferred from the results that the models with only one and two loading machines are not usable since the total waiting time and throughput time per truck of these models are extremely high due to the inlet truck flows outnumber the capacities of the systems. Therefore, the amount of trucks dwelling in these systems would keep increasing over time, unless additional loading machines are added to increase the capacity of the system.

Also, it can be observed that the total truck waiting time, throughput time, and the average queue length dramatically shift from 7.32 minutes, 47.7 minutes, and 0.71 trucks to 42.6 minutes, 82.8 minutes, and 4.29 trucks, respectively, if one loading machine is removed from the merged-queue default model of 4 machines.
5.3 Results and Sensitivity Analysis of the Merged-Queue Cement Loading Process Models with One Additional Loading Channel during Peak and PM Mid-Peak Periods.

So far, it has been observed that although the additional channels effectively reduce truck waiting time and the average number of trucks waiting in the queue, the idle time of machines also increases as well. The additional channels of the model in the previous section were provided to load cement for whole day; however, the extraordinary demand normally occurs during peak period. As a result, the additional loading channels provided in those models seem to be idle during the off-peak period.
The aim of the experiment is to obtain the model that can improve both percent of truck productive time and percent utilization of machines, compared to the default practice. Consequently, further simulation models were developed on the cement loading system by adding one loading channel during 8-hour duration of the peak period and PM mid-peak period to utilize the operation time and cost of the extra loading machines by increasing capacity only during the predicted peak time and shifting the capacity back to the normal level when the predicted peak period is pass.

Table 5-5 Sensitivity analysis on the cement loading process models with one additional loading channel during peak and PM mid-peak periods

<table>
<thead>
<tr>
<th>Number of Machines</th>
<th>Utilization Factor</th>
<th>% Truck Utility</th>
<th>% Machine Utility</th>
<th>Total Related Cost ($)</th>
<th>Waiting Time at site (min)</th>
<th>Total Waiting Time (min)</th>
<th>Total Time of Truck (min)</th>
<th>Loading Time (min)</th>
<th>Avg. Queue Length (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1+1</td>
<td>0.00034</td>
<td>0.00035</td>
<td>0.97938</td>
<td>70,161</td>
<td>697.12</td>
<td>116,342</td>
<td>116,383</td>
<td>23.79</td>
<td>38.32</td>
</tr>
<tr>
<td>2+1</td>
<td>0.00452</td>
<td>0.00464</td>
<td>0.97364</td>
<td>83,343</td>
<td>378.50</td>
<td>8,630</td>
<td>8,670</td>
<td>23.24</td>
<td>37.03</td>
</tr>
<tr>
<td>3+1</td>
<td>0.48607</td>
<td>0.73480</td>
<td>0.66150</td>
<td>93,520</td>
<td>13.66</td>
<td>14.02</td>
<td>52.87</td>
<td>21.85</td>
<td>1.38</td>
</tr>
<tr>
<td>4+1</td>
<td>0.49140</td>
<td>0.89303</td>
<td>0.55027</td>
<td>104,685</td>
<td>4.48</td>
<td>4.86</td>
<td>45.39</td>
<td>23.53</td>
<td>0.45</td>
</tr>
<tr>
<td>5+1</td>
<td>0.39382</td>
<td>0.97608</td>
<td>0.40347</td>
<td>114,419</td>
<td>0.60</td>
<td>0.94</td>
<td>39.24</td>
<td>21.30</td>
<td>0.06</td>
</tr>
<tr>
<td>6+1</td>
<td>0.32693</td>
<td>0.98528</td>
<td>0.33182</td>
<td>124,763</td>
<td>0.17</td>
<td>0.57</td>
<td>38.39</td>
<td>20.81</td>
<td>0.02</td>
</tr>
<tr>
<td>7+1</td>
<td>0.31333</td>
<td>0.98963</td>
<td>0.31661</td>
<td>136,086</td>
<td>0.05</td>
<td>0.42</td>
<td>40.32</td>
<td>22.90</td>
<td>0.00</td>
</tr>
<tr>
<td>8+1</td>
<td>0.29538</td>
<td>0.99080</td>
<td>0.29813</td>
<td>147,102</td>
<td>0.01</td>
<td>0.39</td>
<td>41.89</td>
<td>24.49</td>
<td>0.00</td>
</tr>
<tr>
<td>9+1</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Default (4)</td>
<td>0.35371</td>
<td>0.59324</td>
<td>0.59623</td>
<td>101,186</td>
<td>27.46</td>
<td>27.83</td>
<td>68.41</td>
<td>23.57</td>
<td>1.63</td>
</tr>
<tr>
<td>Merged Queue</td>
<td>0.50085</td>
<td>0.84642</td>
<td>0.59172</td>
<td>101,110</td>
<td>6.98</td>
<td>7.32</td>
<td>47.69</td>
<td>23.34</td>
<td>0.71</td>
</tr>
</tbody>
</table>

The sensitivity analysis results on the cement loading process model with one additional channel during peak and PM mid-peak periods indicate that the two greatest utilization factor values of 0.486 – 0.491 are yielded by two simulation
models: the model of three loading channels with one additional channel during peak hours (3+1) and the model of four loading channels with one additional channel during peak hours (4+1), as shown in Table 5-5, while other models show somewhat significantly less utilization factor values than these two models. The utilization factor trend of the models, which is a series of multiplication between percent truck productive time and percent utilization of machines, is illustrated in Figure 5-9. Once again, the percent of truck productive time after an extra loading channel is added tends to increase with the greater number of loading machines operated and outnumbers the percent of truck productive time of the models without additional server. Also, the total related cost tends to increase with greater number of machines. Similar to the results from the previous section, the percent utilization of machines also decreases when more machines are assigned to operate in the system.

Obviously, when compare the results from the cement loading process models with an extra channel during the peak duration to the model without an extra channel, it can be seen that the percent of truck productive time improves and the percent utilization of machines decreases, for all the models, in various margins. Interestingly, the models that possess small number of loading channels, such as the models of one channel and two channels, and the models with great cement loading capacity, e.g. the model of 5 or more loading channels, seem to have relatively small changes in percent of truck productive time and percent utilization of machines. For example, an additional server during the peak duration only shifts the percent of truck productive time of the model of 5 loading channels from 0.968 to 0.976 and reduces the percent utilization of machines from 0.423 to 0.403. However, the models of 3 and 4 loading channels experience greater changes in percent of truck productive time and percent utilization of machines.
when an extra channel is added. For instance, when an extra loading channel is added to the model of 3 servers, the percent of truck productive time dramatically increases from 0.486 to 0.735, while the percent utilization of machines declines from 0.787 to 0.662. Likewise, the percent of truck productive time increases from 0.846 to 0.893, while the percent utilization of machines declines from 0.592 to 0.550 when an additional loading channel is assigned to the model of 4 servers.

![Graph showing trends of utilization factor](image)

**Figure 5-9** Trends of utilization factor when the number loading machines changes under the condition that one additional server is provided during the peak duration

Also, it can be observed that the total truck waiting time, throughput time, and the average queue length dramatically decrease from 42.6 minutes, 82.8 minutes, and 4.29 trucks to 14.0 minutes, 52.9 minutes, and 1.38 trucks, respectively, if an additional loading channel is provided for the model of 3
machines during 8-hour peak and PM mid-peak periods. In other words, the total truck waiting time, throughput time, and the average queue length decreases by 28.6 minutes per truck, 29.9 minutes per truck, and 2.91 trucks, respectively. The model of the cement loading process using 3 servers with an additional server during the 8-hour peak and PM mid-peak periods is illustrated in Figure 5-10, Figure 5-11, and Figure 5-12.

Similarly, when an additional loading channels are provided during 8-hour peak and PM mid-peak periods for the model of 4 machines, the total truck waiting time, throughput time, and the average queue length decrease from 7.32 minutes, 47.7 minutes, and 0.71 trucks to 4.86 minutes, 45.4 minutes, and 0.45 trucks, respectively. To say, the total truck waiting time, throughput time, and the average queue length decreases by 2.3 minutes per truck, 2.46 minutes per truck, and 0.26 trucks, respectively. The model of the cement loading process using 4 servers with an additional server during the 8-hour peak and PM mid-peak periods can be seen in Figure 5-13, Figure 5-14, and Figure 5-15.

Furthermore, it can be inferred from the results that the models of only 1 and 2 loading machines are not workable since the total waiting time and throughput time per truck of these models are extremely high due to the inlet truck flows outnumber the capacities of the systems. Therefore, the amount of trucks dwelling in these systems would keep increasing over time, unless the capacity of the system is improved.
Figure 5-10 Cement loading system of the merged queue model of 3 loading channels with one extra channel during peak and PM mid-peak periods
Figure 5-11 Cement loading system of the merged queue model of 3 loading channels with one extra channel during peak and PM mid-peak periods (continued)
Figure 5-12 Cement loading system of the merged queue model of 3 loading channels with one extra channel during peak and PM mid-peak periods (continued)
Figure 5-13 Cement loading system of the merged queue model of 4 loading channels with one extra channel during peak and PM mid-peak periods
Figure 5-14 Cement loading system of the merged queue model of 4 loading channels with one extra channel during peak and PM mid-peak periods (continued)
Figure 5-15 Cement loading system of the merged queue model of 4 loading channels with one extra channel during peak and PM mid-peak periods (continued)
5.4 Results and Sensitivity Analysis of the Merged-Queue Cement Loading Process Models with Two Additional Loading Channels during Peak and PM Mid-Peak Periods.

From the previous section, the additional channel during the peak and PM mid-peak periods seems to reduce truck waiting time and the average number of trucks waiting in the queue, especially for the models which operate with 3 and 4 loading channels. However, the idle time of machines tends to increase when the system operates with greater number of servers, especially for those models which operate with 3 and 4 loading channels.

The objective of this experiment is to see if the additional 2 loading channels can improve either the percent of truck productive time or the percent utilization of machines, compared to the default model and the models with one extra channel during the peak duration. As a result, further simulation models were developed on the default cement loading system by providing two extra loading channels during the 8-hour duration of the peak period and PM mid-peak period. Although the additional channel does not seem to significantly reflect the percent of truck productive time and percent utilization of machines for those models operating with five and more servers, compared to the models without an extra server, the simulations were performed on all the models to see the sensitivity of the results.
The sensitivity analysis results on the cement loading process model with two additional channels during peak and PM mid-peak periods indicate that the two models that show the greatest utilization factor are the model of 3 loading channels with two additional channels during peak hours (3+2) and the model of 4 loading channels with two additional channels during peak hours (4+2), in which the utilization factors are 0.481 and 0.478, respectively, while other models show somewhat significantly less utilization factor values than these two models, as seen in Table 5-6. The utilization factor trend of the models, which is a series of multiplication between percent truck productive time and percent utilization of machines, is illustrated in Figure 5-16.

Similar to the results from the previous section, the two extra loading channels, provided during the 8-hour peak duration, lift the percent of truck productive time of the models, compared to those models with one extra channel.
and without extra channel. In other words, the percent of truck productive time for all the models improves and the percent utilization of machines decreases, in various margins, when two extra channels are assigned to operate during the peak and PM mid-peak periods instead of one. Besides, the percent of truck productive time tends to increase concordantly with the increased number of loading machines. Also, the total related cost tends to increase with greater number of machines, while the percent utilization of machines also decreases when more machines are assigned to operate in the system.

Again, the additional 2 servers seem to have very small impacts on the percent of truck productive time and percent utilization of machines for the models that possess 1 channel, and the models with great cement loading capacity, e.g. the model of 5 or more loading channels. To illustrate, an additional server during the peak duration shifts the percent of truck productive time of the model of 5 loading channels from 0.976 to 0.977 and reduces the percent utilization of machines from 0.403 to 0.383.

However, the analysis founds that the parameters in the model which operates with 2 loading machines (2+2) experiences a great leap when the extra two servers are provided during the peak duration, compared to when the model has one additional server. For instance, the percent of truck productive time of the model increases from 0.004 to 0.221 and the percent utilization of machines dumps from 0.974 to 0.851, after another channel was provided during the 8-hour period, lifting the utilization factor from 0.005 to 0.211. Additionally, the total truck waiting time, throughput time, and the average queue length heavily decrease from 3,630 minutes, 3,670 minutes, and 37.0 trucks to 119.6 minutes, 159.1 minutes, and 11.7 trucks, respectively, when two additional loading channels are provided during 8-hour peak and PM mid-peak periods for the model of two machines with
one extra channel. To be specific, the total truck waiting time, throughput time, and the average queue length decreases by 3,510.4 minutes per truck, 3,510.9 minutes per truck, and 25.3 trucks, respectively. The reason why such parameters experience great reduction is that the average inlet truck flow rate is outnumbered by the capacity of the system, when another extra channel is added during the 8-hour peak duration. Moreover, the margin between the average truck waiting time at site and the average total truck waiting time is relatively small since the capacity of the parking space at the loading queue were not reached for substantial amount of time.

Figure 5-16 Trends of utilization factor when the number loading machines changes under the condition that two additional servers are provided during the peak duration
In addition, the models of 3 channels and 4 channels, with one extra channel, experience moderate changes in percent of truck productive time and percent utilization of machines when another channel is added (3+2 and 4+2). For example, when another extra loading channel is added to the model of 3 servers with one extra channel, the percent of truck productive time shifts from 0.735 to 0.771, while the percent utilization of machines declines from 0.662 to 0.624. Likewise, the percent of truck productive time increases from 0.893 to 0.923, while the percent utilization of machines declines from 0.550 to 0.518 when another additional loading channel is assigned to the model of 4 servers with one extra channel.

Obviously, the total truck waiting time, throughput time, and the average queue length slightly decrease from 14.0 minutes, 52.9 minutes, and 1.38 trucks to 11.8 minutes, 51.5 minutes, and 1.15 trucks, respectively, when another loading channel is provided during 8-hour peak and PM mid-peak periods for the model of 3 machines with one extra channel. In other words, the total truck waiting time, throughput time, and the average queue length decreases by 2.2 minutes per truck, 1.4 minutes per truck, and 0.23 trucks, respectively. The model of the cement loading process using 3 servers with two additional servers during peak time (3+2) can be seen in Figure 5-17, Figure 5-18, and Figure 5-19.

Similarly, when another loading channels is provided during 8-hour peak and PM mid-peak periods for the model of 4 machines with one extra channel, the total truck waiting time, throughput time, and the average queue length slightly decrease from 4.86 minutes, 45.4 minutes, and 0.45 trucks to 3.42 minutes, 44.3 minutes, and 0.31 trucks, respectively. In other words, the total truck waiting time, throughput time, and the average queue length decreases by 1.44 minutes per truck, 1.1 minutes per truck, and 0.14 trucks, respectively. The model of the cement
loading process using 4 servers with two additional servers during peak time (4+2) can be seen in Figure 5-20, Figure 5-21, and Figure 5-22.

Figure 5-17 Cement loading system of the merged queue model of 3 loading channels with 2 extra channels during peak and PM mid-peak periods
Figure 5-18 Cement loading system of the merged queue model of 3 loading channels with 2 extra channels during peak and PM mid-peak periods (continued)
Figure 5-19 Cement loading system of the merged queue model of 3 loading channels with 2 extra channels during peak and PM mid-peak periods (continued)
Figure 5-20 Cement loading system of the merged queue model of 4 loading channels with 2 extra channels during peak and PM mid-peak periods
Figure 5-21 Cement loading system of the merged queue model of 4 loading channels with 2 extra channels during peak and PM mid-peak periods (continued)
Figure 5-22 Cement loading system of the merged queue model of 4 loading channels with 2 extra channels during peak and PM mid-peak periods (continued)
5.5 Results and Sensitivity Analysis of the Merged-Queue Cement Loading Process Models with Three Additional Loading Channels during Peak and PM Mid-Peak Periods.

From the previous sections, it has been found that when the capacity of the cement loading system is improved, the percent of truck productive time tends to increase, while the percent utilization of machines tends to decrease. In addition, neither percent of truck productive time nor percent utilization of machines is significantly reflected by the changes in loading capacity when the overall capacity of the model is either higher or lower than the capacity of the model operating with, on average, two to four loading machines.

The aim of this experiment is to see the changes when the additional three loading channels are provided, compared to the models after two extra channels are added, during the peak duration. As a result, further simulation models were developed on the default cement loading system by providing three extra loading channels during the 8-hour duration of the peak period and PM mid-peak period. Since there were relatively small changes occurred on the results of the model operating with more than 5 loading channels; therefore, the experiment in this section focuses only on the results of the models that contain 2, 3, and 4 loading machines during the off-peak duration.

The sensitivity analysis results on the cement loading process model with three additional channels during peak and PM mid-peak periods indicate that the model of three loading channels with three additional channels during peak hours (3+3) shows the utilization factor of 0.474, which is the greatest result among the models simulated in this experiment, as shown in Table 5-7.
Table 5-7 Sensitivity analysis on the cement loading process models with three additional loading channels during peak and PM mid-peak periods

<table>
<thead>
<tr>
<th>Number of Machines</th>
<th>Utilization Factor</th>
<th>% Truck Utility</th>
<th>% Machine Utility</th>
<th>Total Related Cost ($)</th>
<th>Waiting Time at site (min)</th>
<th>Total Waiting Time (min)</th>
<th>Total Time of Truck (min)</th>
<th>Loading Time (min)</th>
<th>Avg. Queue Length (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2+3</td>
<td>0.21736</td>
<td>0.28027</td>
<td>0.77555</td>
<td>90,480</td>
<td>96.57</td>
<td>102.79</td>
<td>142.81</td>
<td>23.01</td>
<td>9.77</td>
</tr>
<tr>
<td>3+3</td>
<td>0.47352</td>
<td>0.79113</td>
<td>0.59854</td>
<td>101,235</td>
<td>10.37</td>
<td>10.73</td>
<td>51.39</td>
<td>23.66</td>
<td>1.05</td>
</tr>
<tr>
<td>4+3</td>
<td>0.44540</td>
<td>0.93319</td>
<td>0.47728</td>
<td>111,753</td>
<td>2.56</td>
<td>2.91</td>
<td>43.53</td>
<td>23.60</td>
<td>0.26</td>
</tr>
<tr>
<td>Default (4)</td>
<td>0.35371</td>
<td>0.59324</td>
<td>0.59623</td>
<td>101,186</td>
<td>27.46</td>
<td>27.83</td>
<td>68.41</td>
<td>23.57</td>
<td>1.63</td>
</tr>
<tr>
<td>Default with merged queue (4)</td>
<td>0.50085</td>
<td>0.84642</td>
<td>0.59172</td>
<td>101,110</td>
<td>6.98</td>
<td>7.32</td>
<td>47.69</td>
<td>23.34</td>
<td>0.71</td>
</tr>
</tbody>
</table>

Interestingly, it can be found from the results that the model operating by using 3 loading machines with 3 extra machines during peak duration (3+3) yields the average throughput time of 51.4 minutes per truck, which indicates that the throughput time provides insignificantly small changes, compared to the throughput time of 51.5 minutes per truck from the same model with only 2 extra servers. Although the average total waiting time and the average queue length reduce from 11.8 minutes and 1.15 trucks to 10.7 minutes and 1.05 trucks, respectively, the average loading time increases from 22.7 minutes to 23.7 minutes, due to an inclusion of the channel 27, of which the loading time is the highest among the loading channels. In addition, it can be observed that the average number of operating servers for the model which operates by using 3 loading machines with 3 extra machines during peak duration (3+3) equals the number of servers used by the default model and the default model after loading queues are merged; however, the results of these models are different. To say, the lowest average waiting time, throughput time, and queue length, are yielded by the default model with merged queue, followed by the model of 3 loading machines with 3 extra machines during peak duration (3+3), and the default model, respectively.
The model of the cement loading process using three servers with three additional servers during peak time (3+3) can be seen in Figure 5-23, Figure 5-24, and Figure 5-25.

The reason why such a result occurs could be the fluctuation of inlet truck flow rate during the 16 hours of the off-peak and PM mid-peak periods could not be completely covered by the capacity of only 3 loading channels. On the other hand, despite the additional 3 channels can cope with the high demand during the 8-hour peak and PM mid-peak periods, the capacity of 6 loading machines during the period seems to be excessive that create abundant of idle time for the loading machines. In addition, the demand during the 8-hour peak duration is not only non-uniformly distributed over the period but also fluctuate from time to time, as a result of uncertainty in simulation and random number generation.
Figure 5-23 Cement loading system of the merged queue model of 3 loading channels with 3 extra channels during peak and PM mid-peak periods
Figure 5-24 Cement loading system of the merged queue model of 3 loading channels with 3 extra channels during peak and PM mid-peak periods (continued)
Figure 5-25 Cement loading system of the merged queue model of 3 loading channels with 3 extra channels during peak and PM mid-peak periods (continued)
Chapter 6
DISCUSSION AND CONCLUSIONS

According to the results and the sensitivity analyses shown in the previous sections, six models which yield high utilization factor, range from 0.474 – 0.501, were selected to be considered in the further analysis. The six models of interest are:

1) The default model with merged loading queue.
2) The model of 3 channels with 1 extra channel during peak duration (3+1).
3) The model of 3 channels with 2 extra channels during peak duration (3+2).
4) The model of 3 channels with 3 extra channels during peak duration (3+3).
5) The model of 4 channels with 1 extra channel during peak duration (4+1).
6) The model of 4 channels with 2 extra channels during peak duration (4+2).

The results from these models were summarized and compared for the sake of selecting a model that can improve the overall performance of the cement loading process and satisfy both manufacturing plant and customers. The results of those models are summarized, as seen in Table 6-1.

Table 6-1 Comparison of results among the interest models

<table>
<thead>
<tr>
<th>Number of Machines</th>
<th>Utilization Factor</th>
<th>% Truck Utility</th>
<th>% Machine Utility</th>
<th>Total Related Cost ($)</th>
<th>Waiting Time at site (min)</th>
<th>Total Waiting Time (min)</th>
<th>Total Time of Truck (min)</th>
<th>Loading Time (min)</th>
<th>Avg. Queue Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>3+1</td>
<td>0.48607</td>
<td>0.73480</td>
<td>0.66150</td>
<td>93,520</td>
<td>13.66</td>
<td>14.02</td>
<td>52.87</td>
<td>21.85</td>
<td>1.38</td>
</tr>
<tr>
<td>3+2</td>
<td>0.48080</td>
<td>0.77105</td>
<td>0.62357</td>
<td>97,382</td>
<td>11.41</td>
<td>11.78</td>
<td>51.47</td>
<td>22.69</td>
<td>1.15</td>
</tr>
<tr>
<td>3+3</td>
<td>0.47352</td>
<td>0.79113</td>
<td>0.59854</td>
<td>101,235</td>
<td>10.37</td>
<td>10.73</td>
<td>51.39</td>
<td>23.66</td>
<td>1.05</td>
</tr>
<tr>
<td>Default with merged queue (4)</td>
<td>0.50085</td>
<td>0.84642</td>
<td>0.59172</td>
<td>101,110</td>
<td>6.98</td>
<td>7.32</td>
<td>47.69</td>
<td>23.34</td>
<td>0.71</td>
</tr>
<tr>
<td>4+1</td>
<td>0.49140</td>
<td>0.89303</td>
<td>0.55027</td>
<td>104,685</td>
<td>4.48</td>
<td>4.86</td>
<td>45.39</td>
<td>23.53</td>
<td>0.45</td>
</tr>
<tr>
<td>4+2</td>
<td>0.47834</td>
<td>0.92281</td>
<td>0.51836</td>
<td>108,348</td>
<td>3.05</td>
<td>3.42</td>
<td>44.33</td>
<td>23.90</td>
<td>0.31</td>
</tr>
</tbody>
</table>
According to the comparison between the qualified models, it can be seen that the model of 3 channels with 1 extra channel during peak duration (3+1) causes the lowest percent of truck productive time, highest truck waiting time, highest throughput time, and longest queue length among the selected models, even though it is the best model that utilizes the machine with the least related cost and greatest percent utilization of machines.

In addition, it can be observed that the model 3+3 yields the percent utilization of machines of 0.599, which is close to the percent utilization of machines of 0.592 that obtained by the default model with merged queue. Also, the total related cost of the model 3+3 outnumbers the total related cost of the default model with merged queue by $135 during the 350 days of simulation, or only $0.39 per day; however, the model 3+3 has lower performance in terms of truck waiting time, throughput time, and queue length, compared to the default model with merged queue. For instance, average total waiting time, throughput time, and queue length of the 3+3 model exceed the results from the default model with merged queue by 3.41 minutes, 3.70 minutes, and 0.34 trucks, respectively. Therefore, the model 3+3 should be eliminated from the consideration, as a result of the above reasons.

On the other hand, the model of 4 loading channels with 2 extra channels during peak duration (4+2) yields the percent of truck productive time, truck waiting time, throughput time, and average queue length of 0.923 percent, 3.42 minutes, 44.33 minutes, and 0.31 trucks, respectively, which are the best results among the selected models; however, the maximum related cost and lowest percent utilization of machines, among the models of interest, are shown by this model, as seen in Table 5-8. Although the $108,348 related cost and lowest percent utilization of machines are induced by the model 4+2, the total related cost
generated by the model during the 350 days of simulation time exceeds cost from the existing practice by $7,162, or only $20.5 per day. However, the truck waiting time, throughput time, and average queue length of the model decreases from the default model by 87.7%, 35.2%, and 81.0%, respectively. Besides, the percent of truck productive time improves from the default model by 32.96%, while the percent utilization of machines decreases by only 7.8%. Similarly, compared to the default model with merged queue, the model 4+2 yields the lower truck waiting time and average queue length by 53.3% and 56.3%, respectively, while the additional related cost is increased by $20.7 per day.

Figure 6-1 Chart shows the number of trucks in the loading queue over time for the model using 3 servers with an additional server during peak and PM mid peak periods
Figure 6-2 Chart shows the number of trucks in the loading queue over time for the model using 3 servers with 2 additional servers during peak and PM mid peak periods

Figure 6-3 Chart shows the number of trucks in the loading queue over time for the model using 3 servers with 3 additional servers during peak and PM mid peak periods
Figure 6-4 Chart shows the number of trucks in the loading queue over time for the model using 4 servers with an additional server during peak and PM mid peak periods.

Figure 6-5 Chart shows the number of trucks in the loading queue over time for the model using 4 servers with 2 additional servers during peak and PM mid peak periods.
Furthermore, among these six selected models, the model 4+2 seems to be the most effective model in terms of capability to minimize the amount of trucks in the loading queue during the peak period. The average queue length of the default model with merged queue, the model 3+1, the model 3+2, the model 3+3, the model 3+3, and the model 4+1 are shown in Figure 5-6, 6-1, 6-2, 6-3, and 6-4, respectively. Obviously, although the models with higher capacity tend to have shorter queue length during the peak duration, as shown by the shorter peaks, the effects from the peak flow still exist in the default model with merged queue, the model 3+1, the model 3+2, the model 3+3, the model 3+3, and the model 4+1. However, among the selected models, the model 4+2 is found to be the only model that can completely eliminate the effect from the truck flow during the peak duration since its queue length seems to be stable and the peak disappears from the queue length chart, due to the adequate loading capacity provided, as shown in Figure 5-5.

Consequently, the model of 4 channels with 2 extra channels during the 8-hour peak and PM mid-peak periods (4+2) is suggested for making an improvement on the cement loading process at the Asia Cement Plant due to its capability to reduce truck waiting time, throughput time, and queue length, with relatively low additional related cost. To do so, the queuing system of the loading queues need to be improved by merging queues together as a truck pool in order to eliminate unbalance truck waiting time from multiple queues. Besides, two additional loading channels need to be added during 2 PM – 10 PM, daily, in order to effectively improve truck flow, shorten queue length, and reduce truck waiting time and throughput time.
BIBLIOGRAPHY


<http://www.asiacement.co.th/ENG/Our+Plants/Asia+Cement+Plc>


APPENDIX

Asia Cement Plant is located in Saraburi Province, a city in the central region of Thailand, on an area of more than 400 acres. In 1993 the first production line was started with an installed capacity of two million tons of cement per year. In 1997, the second production line was constructed with an installed capacity of three million tons of cement per year. Both production lines adopt the dry process technology to produce three types of cement: ordinary Portland cement type 1, mixed cement, and masonry cement. Nowadays, the plant consists of two production lines, producing cement at a current installed capacity of five million tons of cement per year, alongside with a plant-own limestone quarry located on the mountain adjacent to the plant. The cement loading and distribution sector also consists of two cement loading lines to serve cement from 8 silos, with a total capacity of 100,000 tons, to customers (Asia Cement PLC, 2007).

Figure A-1 Cement loading sector of the Asia Cement Plant
Figure A-2 A bulk cement truck waiting in the loading queue

Figure A-3 The control diagram of the cement loading process at line 2
Figure A-4 The control diagram of the cement loading process at line 1

Figure A-5 The weighbridge station
Figure A-6 The loading queue at the line 1

Figure A-7 Trucks are loading with bulk cement at the loading channels
Figure A-8 Trucks are loading with bulk cement at the loading channels

Figure A-9 A cement loading channel with a weighbridge at the base (left), A bulk cement loading machine (right)
Figure A-10 The cement loading machine is attached to the cement truck