Capability Analysis and throughput improvement of a Rail Load-out station at Leeuwpan coal mine

by

GEORGINAH K. TSITA
28011806

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Abstract

The outsourcing of coal at Leeuwpan coal mine is the primary factor driving the objectives of this project. The Rail Load-out station at Leeuwpan coal mine along with the processes and operations involved in the consignment of coal to their customers plays a vital role in the company logistics. It is therefore highly imperative that there are always improvement efforts to ensure the delivery of a reliable product as well as satisfactory levels of productivity.

In this project, Discrete-Event Simulation is used to determine the capability of a load out station at Leeuwpan Coal mine. A thorough analysis is to be done on the results and an exploration approach taken to identify productivity improvement opportunities. A Theory of Constraints analysis is done on the current and improvement scenarios to exploit system constraints as well as to re-schedule client arrivals/loading where resources are limited and throughput improvement scenarios are presented.

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Chapter 1

Introduction

1.1) Project Background

The Leeuwpan coal mine, one of Exxaro Resources' coal operations, is situated approximately 80km south-east of Pretoria in the Mpumalanga province. This open-pit mine uses modified terrace configurations as well as truck and shovel operations which produce 3Megatons per annum of Metallurgical and power station coal.

A crucial component of the mine is the train Load out station, which, along with its related surrounding operations and resources, plays an important role in the company logistics. Logistics, as stated by Langley et al. (2008) is "the process of anticipating customer needs and wants; acquiring the material necessary to meet those needs and wants; optimizing the goods- or service-producing network to fulfill customer requests; and utilizing the network to fulfill customer requests in a timely manner." The driving factor of all the business elements and operations at Leeuwpan mine is indeed customer demand and it is essential that operations are optimized and effectively run and that the coal acquisition processes and results are reliable and adequate enough to meet customer demand.

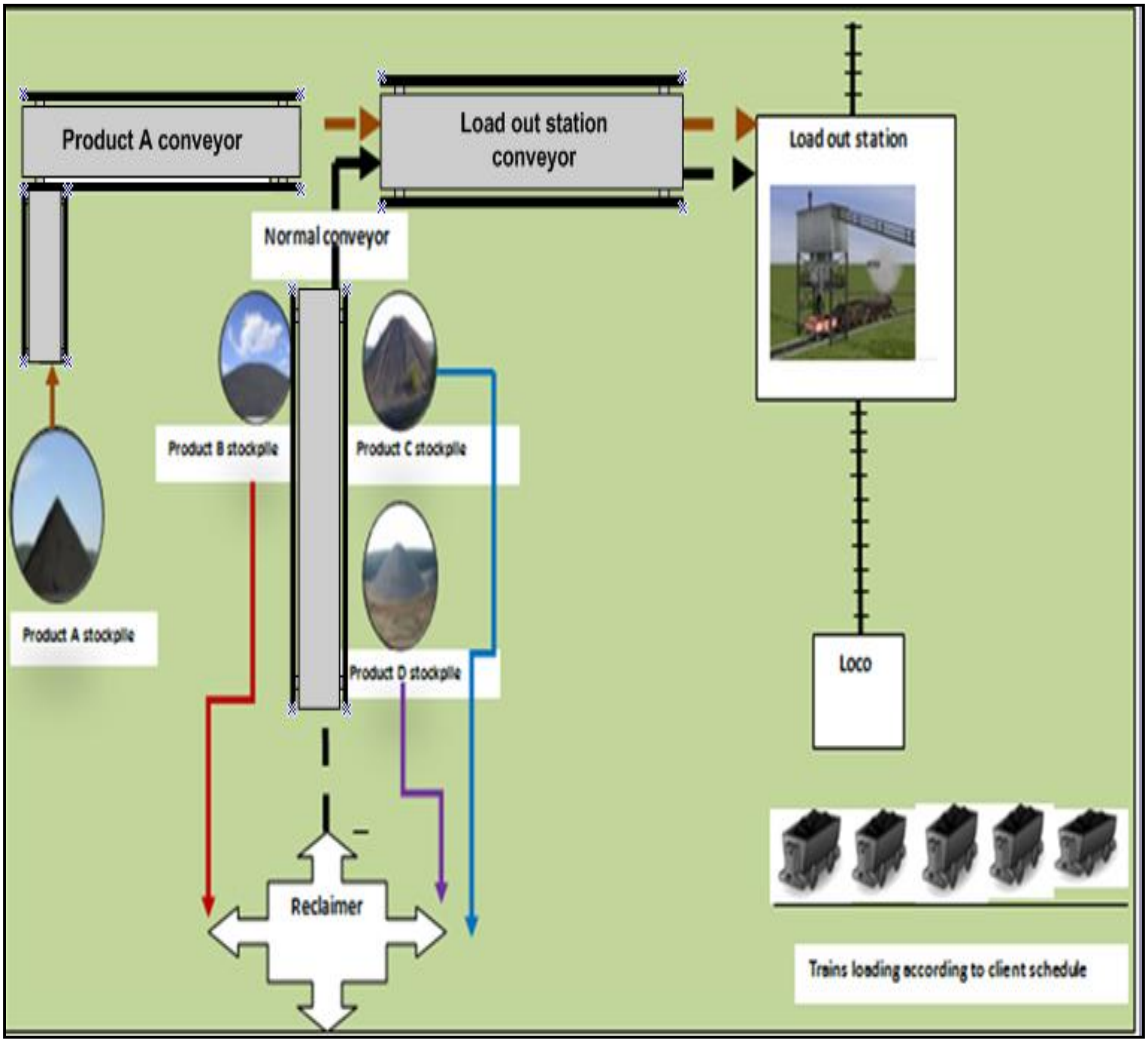
1.2) Load out station operations

The trains and railways required are managed and supplied by the Transnet Freight Rail (TFR) association. Trains are received from the rail loop and sent to the Load out station, where there can only be one train loading at a time. The loading and arrival of trains depends on the train Turn Around Times (TAT times), which include the time from which the train is received from the rail loop, the loading time in the load out station and the time that it takes till the train is handed over (Hand over time).

The operations involved to allow feed into the load-out station involve the feeding of the different coal products from the stockpiles via conveyor belts into the Load out station. The Product is fed and loaded onto the trains according to a client and product schedule. Only one product at a time can be run on the conveyor belts, fed into the Load out station and unloaded onto a train situated in the Load out station.

The following diagram illustrates the resource layout, material flow and train operations:

Figure 1: Process Layout



1.3) Problem Statement

The weekly schedule currently accommodates the arrival of 26 trains per week. The consistency of the current schedule has to be investigated in order to determine its efficiency with regards to operational time and throughput delivery. There could be constraints in the current operational scenario which could cause inconsistencies with regards to throughput obtained in a month and therefore have to be identified and eliminated. Resources utilization has to be efficient enough such that there is no under or over utilization of resources. Planned maintenance times also have a major impact on the loading schedule and have to be analyzed to investigate their effect on system performance.

1.4) Project Aim

The aim of the project is to determine the capability of the Rail Load-out Station at Leeuwpan Coal mine through a simulation model. The simulation model should aid in the exploration of the facility's capability, identification of process constraints and also help identify productivity improvement opportunities.

The proposed improvement scenarios aim to:

- Improve the system performance (Increase throughput)
- Identify and alleviate the over-utilization of resources
- Eliminate the risk and existence of unforeseen system constraints or bottlenecks
- Reduce the chances of failure to meet proposed changes and expectations by performing an experimental analysis on all proposed alternatives

The methodology that will be carried out to pursue the project aim is:

- A literature survey that will be used as a guide to understanding the problem context and solution approaches used for similar problems.
- Data collection for use in the simulation model that will help in the analysis and experimentation of the current and improvement scenarios.
- A Theory of constraints analysis that will help in the identification of bottlenecks and system constraints.
- Development of Improvement scenarios that will potentially achieve the overall project aim.
- A recommendation conclusion with regards to the final and appropriate improvement scenario.

Chapter2

Literature Review

2.1) Simulation

2.1.1) Introduction to simulation

2.1.1.1) What is simulation?

Simulation, as defined by Chen et al (2002) is the imitation of real-life processes to allow the user to gain relevant insight on the functionality of the process as well as to provide quantitative information needed to make decisions regarding the process. This definition of simulation goes beyond the classic definition as mentioned by McLeod (1968); "Man has been simulating since his brain developed the power to imagine", in that there are additional tools to be used besides just the imagination. McLeod (1968) defines simulation as the utilization and development of models to assist in the analysis and assessment of dynamic real-life processes and systems. A system, as defined by Kelton et al (2007). , is a collection of resources or entities which work together to accomplish a certain goal. The interacting components or entities that make up the system receive input and function relationally to deliver a desired output. According to McLeod (1968), although computers are not entirely necessary for simulation, they are an advanced and best tool in the field of simulation. Kelton et al (2007) defines simulation as a vast collection of methods and implements to imitate the real-life behaviors and conditions of systems and processes with the aid of computers and the relevant software. Banks et al (1995) states that the simulation or imitation of real-world systems or processes is to be done over time. Simulation basically entails the generation of a conceptual history of the system as well as the analysis of the conceptual process to draw conclusions regarding the operations and process characteristics of the system. A simulation model is usually built based on a set of assumptions which are expressed in symbolic, logical or mathematical relations between the relevant system components. A complete and validated simulation model is useful to investigate various alternative scenarios with regards to the operation of the system, which would then help to investigate the impact of potential changes made to the system. According to Banks et al (1995)., simulation is useful both as an analysis tool; to investigate the effect of potential or proposed changes ,and as a design tool to determine the performance of newly implemented systems under varying conditions.

2.1.1.2) Brief history of simulation

History

The development of simulation is evident in its history; as it began in the late 1950's and 1960's as a costly and unfamiliar tool used only by large steel and aerospace companies which had potential investments and decisions to make regarding the benefits or success of the investments in certain projects. During the 1970's and early 1980's, the growing accessibility of computers led to the increasing popularity and value of simulation in other industries. Simulation made its mark in the Business world in the late 1980's due to the development of animation as well as the introduction of personal computers. The 1990's saw the advancement and maturing of simulation with the improvement of software features as well as the general technology advancement. Sadowski et al (2007).

2.1.1.3) Purpose of Simulation

Simulation is useful for the evaluation of process and operational alternatives which could increase the productivity or efficiency without making any consignments in capital or resources and without the disruption of the current operational system; Garcia (2000). Simulation modeling and analysis of systems is done for numerous purposes (Pedgen et al, 1995):

- To gain necessary insight into the system operations as well as to gain information without disrupting the actual system
- To develop resource or operational policies from the analysis of the results to improve the performance of the system operations
- To test new or proposed concepts without the implementation of any changes where investment losses could be saved
- To verify and reinforce analytic solutions and their methodologies

2.1.2) Application and use

As stated by McLeod (1968); “the application areas of simulation are as broad as human Endeavour itself”. From their establishment, simulation methods were used in the aerospace industry and have become popular in the fields of operations research, process and manufacturing industries, as well as biological sciences. Examples of Areas of application for simulation modeling according to Nelson et al (1995) are: Manufacturing systems, Public systems, Transportation systems, Construction systems, Restaurant and entertainment systems, Business process re-engineering, Food processing and Computer system performance. The following is a table that represents the abovementioned areas of application along with a list of the subject matter within the respective areas.

Table 1: Simulation Application areas

Manufacturing systems • Material handling systems • Rapid manufacturing • Inventory cost model for ‘JIT’ production • Inventory tracking of Kanban production systems	**Restaurant and Entertainment systems** • Quick service traffic analysis • Determination of labour requirements • Franchise opportunities
Public systems • Healthcare • Military • Natural Resources (Environment)	**Business process reengineering** • Integrating BPR with work flow • Business process modelling and analysis tool
Transportation systems • Cargo transfer • Container port operations • Toll plaza lane staffing (demand based)	**Food processing** • Capacity expansion • Evaluating international competitiveness

Construction systems	Computer system performance
• Earthmoving/ strip mining • Cable-stayed bridges • Strengthening the design/construction interface	• Heterogeneous networks • Evaluating large-scale system performance • System architecture (Client/server)

According to Johangirian et al. (2009),"Simulation is the second most widely used tool in operations management and can be applied to operational fields such as defense, engineering, healthcare, services and manufacturing. As far as the coal supplying facilities are concerned, the train load-out stations and all related operations can be optimized and simulated in order to reach a solid and reliable conclusion to the analytical studies done on all the operational processes involved. The application and utilization of simulation in all fields mentioned allows for the simulation, optimization, improvement and control of all systems and operations in order to reach solid and reliable conclusions to the analytical studies done on all the operational processes involved.

2.1.3) Types of simulation

According to Kelton et al (2007), an effective way to classify simulation is along three dimensions, namely: Deterministic versus Stochastic, Static versus Dynamic and Continuous versus discrete simulation. Models, in general can be classified as either mathematical or physical; with mathematical models representing systems by using mathematical equations or some standardized symbolic notation. A simulation model, according to Carson et al (1995), is a type of mathematical model representing a system.

2.1.3.1) Deterministic versus Stochastic

A deterministic model consists of inputs which represent system arrivals which are not random. As a result, the model will result in a collection of inputs that are unique. A stochastic model on the other hand comprises random variables; Kelton (2007). The result of random inputs into the model would result in random outputs, which according to Bank et al (1995) "can only be considered as estimates of the true system characteristics."

2.1.3.2) Static versus Dynamic

Static simulation modeling is often referred to as Monte Carlo simulation modeling; in this kind of modeling, time does not play a natural role. The system being modeled is represented at a particular point in time; Law et al (2005). Dynamic simulation usually entails most operational models and is a representation of the system as it changes over time. Dynamic simulation is the ultimate capacity assessment method in the exploration of the effects of potential system changes to determine optimum process efficiency; Nugent (2007). A capacity study in this context allows a user to determine how many trains can be able to operate in a given infrastructure/facility during a certain time interval with all given operational requirements and constraints, Tsai et al. (2000).

2.1.3.3) Continuous versus Discrete

With regards to the classification of systems as either discrete or continuous, it has been stated by Law et al (1991) that few systems are indeed definitely discrete or continuous, but because one type of change often overpowers another, it is often possible to define a system as either discrete or continuous. In a continuous system, the system state or variables continuously change with time as the system progresses; Kelton et al (2007). Where continuous and discrete elements are present in the same system, the model representing the system is known as a mixed continuous-discrete model; Kelton (2007). According to Chen et al (2002), Discrete-event simulation is a rapid representation of state variables which change at certain discrete time points. Werker et al (2009) states that DES models use random numbers to imitate the intrinsic variability in the complex processes of the systems they represent.

2.1.4) Advantages and Disadvantages of simulation

2.1.4.1) Advantages

Simulation has grown to become a versatile, popular, powerful and highly ranked operations research tool mainly because it has the capability to handle complex models of accordingly complex systems. Advances in computer hardware and software have contributed in a huge way to the growth of simulation in such a way that the approach to the utilization of simulation has changed from an error-disposed, laborious, low-level programming domain to a tool that is convenient and enables valid and efficient decision making; Sadowski et al (2007). According to Tofts (1998); a major advantage to simulation is that the approach taken is experimental, although unfortunately, the results cannot be guaranteed to more than statistical limits. The ability of computer simulations to make conceptual simulation runs in a compressed amount of time makes it possible to model systems that actually run over months or years. The capability to experiment with large system in a compressed amount of time makes it possible for the user to run multiple replications of every simulation in order to make the system analysis statistically reliable; Chung (2004). Another aspect that makes simulation advantageous is the fact that it requires less analytical expertise and provides opportunities to work on a wider variety of fields and systems. Simulation possesses the ability to dynamically animate the system operations and resources, which limits the tedious text and numerical presentation of systems; Chung (2004). The experimental approach to simulation makes it safer with regards to a guarantee in the control of the experimental conditions whereas it would be less likely to have much control when experimenting on the actual system; Law et al (2005). One other useful advantage of simulation, according to Bank et al (2005) is that it allows constraint and bottleneck analysis where resources or materials are being unreasonably delayed in the system.

2.1.4.2) Disadvantages

Although there are many advantages to the use of simulation, there are also some advantages to simulation which are linked to the expectation of the user rather than the process of modeling and analyzing the system; Chung (2004). The input of inaccurate data into the simulation model will definitely result in the output of inaccurate data; this means the user should give as much attention to the collection of practical and correct data as to the development of the simulation model. Simulating complex systems with numerous components and interactions does not at all guarantee less complex simulation results. Assumptions, simplification or breaking down of the system elements is therefore necessary for the development of a fairly simple model results within a reasonable amount of time. Simulation, however, does not solve system problems; it merely provides the user with potential solutions to the problem. It is thus, up to the user , managers and all stakeholders to establish investments in order to implement the necessary changes needed to improve the system operation; Chung et al (2004). The development of simulation models is often time-consuming and sometimes expensive, along with which there is pressure to meet deadlines and also to build a valid representation of the system. According to Law et al (2005); a simulation model will provide irrelevant results without a valid representation of the system. Banks et al (1995) mentions the requirement for special training as well as the difficulty in the interpretation of simulation results as some of the disadvantages to simulation modeling.

2.1.5) Why Discrete-event simulation?

As was mentioned earlier in the literature study, Discrete-event simulation (DES) rapidly represents state variables which change at certain time points. According to Albrecht (2010), a precise description of the nature of the state changes as well as the time at which the changes occur is mandatory. The actions followed by the DES model are regulated by a set of operational procedures and rules based on the real-life system being modeled; Shengnan (2008). DES models use random numbers to imitate the intrinsic variability in the complex processes of the systems they represent.

The abovementioned definitions and descriptions of DES models enable the motivation of the utilization of DES modeling for this project. The main variable considered is amount of train arrivals in and out of the system. This number will change at certain discrete time points based on the defined schedule specified in the model. The DES model also enables the definition of all operational rules which will ensure that all arrivals/entities in the system perform as specified (what is required and when it is required). The inputs (data distributions) specified into the model provide the model with a baseline for the random numbers used to imitate the intrinsic variability in the complex processes of the system they represent. Although the sub-systems involved in the model which facilitate the product flow (loading duration, amount of product loaded), depict a continuous system, the Arena software package used in this project has the functionality to model continuous operations within a Discrete-event system.

2.1.6) Simulation software

According to Banks (1991); the selection of a suitable software package is an essential but difficult task for companies as a result of the availability of numerous software packages with distinct features. The complexity of soft ware selection lies in the fact that there are different classes of simulation modeling tools, and within these classifications are different capabilities and levels of advancement suitable for processes and systems according to the nature and operational needs of the system. According to Verma et al (2007); the distinct properties, including the modeling approaches and strategies of each simulation package are some of the elements that make the selection and evaluation of simulation packages so complex.

2.1.6.1) Features

The discussion of important features of simulation software by Haider and Banks (1986) and Banks et al (1991) is as follows:

The simulation software features are classified into inputs, processing, output, support and cost.

2.1.6.1.1) Input Features

Important features with regards to inputs include: The software's ability to interface and communicate universally with other software kinds, the capability to analyze empirical and mathematical input distributions, Portability, Easily understandable modeling terminology (syntax), Flexibility with regards to inputs, Flexibility and conciseness in modeling as well as an Interface debugger.

2.1.6.1.2) Processing Features

Important processing features include: Reasonable execution speed, Model size suitable for standard computer capabilities, Material handling capabilities, Random variable generators or distributions, Independent Replications, Attributes, Variables, Programming and conditional routing.

2.1.6.1.3) Output features

Necessary output features include: Standardized and customized reports, confidence intervals to measure the desired level of performance, Business graphics, File creation, Data base maintenance and Tracing capability.

2.1.6.1.4) Environmental features

It is imperative that the simulation software provides environmental and user friendliness in terms of: Ease of use, Ease of learning, Online help, Animation functionality and Customer support.

2.1.6.1.5) Cost

The cost feature involves: The purchase of the software package, training resources required and time spent training users as well as the time spent developing the simulation model. According to

Andradóttir et al (1997), companies should select software analogous to what they can afford and what software features are crucial for the type of processes or systems they operate.

The requirements of every user with regards to software features are significantly different, therefore, although one should look into what features and criteria are relevant for a simulation software package, an overall process should be followed to select the most suitable software package for the company; Hammann and Markovitch (1995).

Steps to selecting the suitable simulation software: (www.goldsim.com)

1. Establish a need and commitment to invest in simulation software
2. State and classify all problems to be solved
3. Determine the general tool required to solve the stated/ classified problems
4. Conduct an initial survey of all potential solutions to the problems
5. Develop functional requirements
6. Select an initial set of tools that could best meet the functional requirements
7. Conducts a detailed evaluation of the tools selected in step 6 and select a solution.

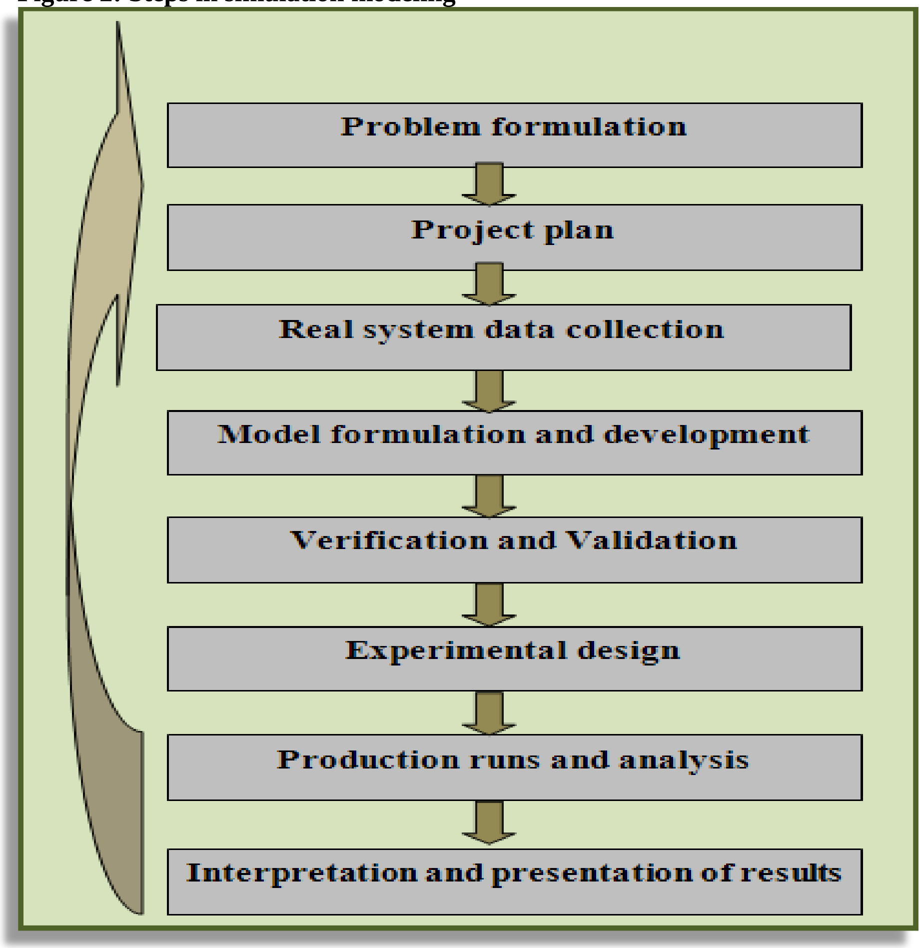
2.1.6.2) Arena

The selected software package for this project provides the user with a decision support tool that has both the necessary capabilities of a potentially suitable software package as well as a user friendly interface for model development; Hammann et al (1995).The development of Arena models usually entails a single modeling paradigm termed process orientation. Arena provides the user with the standard features discussed earlier in the review including a two- dimensional, two-step process in the system animation.

2.1.7) Simulation modelling steps

In order to have a successful implementation or reconfiguration of a system with the aim of optimizing system performance, preventing the over-use of resources, eliminating unforeseen system constraints and reducing the chances of failure to meet system specifications; a strategic approach has to be taken in simulation modeling; Andradóttir et al (1997). The following steps, concluded from Andradóttir et al (1997) and Banks et al (1995) can be followed as a guideline to a thorough and coherent simulation study.

Figure 2: Steps in simulation modeling



2.1.7.1) Problem formulation

It is highly crucial that a priority is given to understanding what is to be achieved through the simulation study as this is a fundamental step in delivering a meaningful simulation project; Chung (2004). Banks et al (1995) states that the analyst should clearly understand the problem as presented by the policymakers or similarly that the policymakers must understand and acknowledge the problem formulation if presented by the analyst. Reformulation of the problem is possible with the progression of the study as a result of difficulty in analyzing the nature of the problem. Chung et al (2004) mentions that every problem formulation should be composed of a formal problem statement, system orientation as well as the establishment of specific project objectives.

2.1.7.2) Project plan

The success or failure of the project could depend highly on the quality of the project plan. The project plan proceeds only once the go-ahead has been given by the commissioning stakeholders and managers. Fundamental concepts of good project management include project parameters (time, cost and technical performance), project life cycles and project stakeholders; Chung (2004).

2.1.7.3) Real system data collection

Data collection is based on the performance of the current system, input variables as well as the specifications made on the system; Andradóttir et al (1997). The input data collected is obtained in real time via time studies or the use of historical data records. Theoretical distributions must be fitted to the data to obtain a realistic collection of the sample data; Chung (2004).

2.1.7.4) Model Formulation and development

Model formulation entails the schematic representation of the system before translation into the simulation software language, which would entail the development of the model into the selected software package; Banks et al (2005).

2.1.7.5) Verification and Validation

Verification is intended to evaluate whether the software is performing adequately according to system specifications (i.e. varying results according to input parameters as well as input ranges and the nature of inputs). Model validation is the comparison of model results under current operating conditions with the real system performance. According to Andradóttir et al (1997), model validation promotes confidence in the model and also ensures that the model assumptions are complete and correct.

2.1.7.6) Experimental Design

Experimental design allows the modeling of system alternatives. Factors associated with experimental design are replication lengths, cycle lengths and the number of replications to be run; Andradóttir et al (1997).

2.1.7.7) Production runs and analysis

Measures of performance are estimated by the relevant number of production runs and their resulting statistical analyses; Banks et al (1995). The relevance of the results analysis is to provide the analyst with the necessary decisional recommendations with regards to the project objectives; Chung (2004).

2.1.7.8) Interpretation and presentation of results

A concluding step in the simulation modeling process is a presentation of the simulation project conclusions and recommendations in the form of a formally compiled project report including all necessary detail essential to present a well comprehended and professionally relevant simulation study; Chung (2004).

2.2) Theory of Constraints

The Theory of Constraints (TOC), proposed by Dr. Eli Goldratt in 1986, is a valuable technique in modern Operations management aimed at the overall management of operating systems and is sometimes referred to as synchronous manufacturing. According to Jacobs et al (2009), the idea behind synchronous manufacturing is the integration of any process operation to ensure successful attainment of the firm's profit goal. Goldratt's idea of a successful firm is one that sets and reaches an ultimate goal to make money. The definition of performance measurements, according to Chase et al (2009) is with respect to Financial and Operational measurements. Financial measurements entail Net Profit, Return on Investment and Cash flow; while Operational measurements are made up of Throughput, Inventory and Operating expenses. Chase et al (2009) defines a firm's goal in terms of Operational measurement as "the increase in throughput while simultaneously reducing inventory and reducing operating expense". The definition of productivity by Chase et al (2009) is; "all actions that bring a company closer to its goals." TOC introduces a concept of thinking globally in terms of the system as a whole and acting locally to reduce activity duration with the utilization of global time; Wei et al (2001). According to Radovilsky (1997), the fundamental of the theory involves the identification of system constraints and decision making about how to operate around these constraints to synchronize the production process or the operation of the system as a whole. Workers, machines, market, demand, regulations and company policies are examples of system constraints. A bottleneck is a physical constraint which has a capacity that is less than or equal to the demand placed on it. In order to avoid the deviation of the actual product flow from the planned product flow, it is essential to identify Capacity Constrained Resources (CCR) and proceed to place control points associated with the CCR's called Drums. The essential and central part of the drum-buffer-rope technique involves the placing of time buffers to protect the system flow from inevitable changes caused by disruptions in the manufacturing flow process. Certain approaches exist in the TOC which can be used to estimate the time buffer size; Watson et al (2007). The following steps mentioned by Chase et al (2007) must be followed in the implementation of TOC to balance the product flow in the production system:

1. Identify the system constraint
2. Exploit the system constraint
3. Subordinate everything else to the project constraint
4. Elevate the project constraint
5. If in the previous step, a new constraint has been uncovered, repeat the process. Do not let inertia become the project constraint.

The combination of current TOC concepts and traditional project management tools is useful for resources-constrained project management modeling for project planning, implementation and control; Wei et al (2001). The TOC has proved to be successful for several companies by aiding in the achievement of significant Work-in-process reduction, improvement in performance scheduling as well as substantial profit increase and therefore serving as a valuable addition or substitute for well-established manufacturing techniques such as Just-in-time (JIT) and Material Requirements Planning (MRP).

Why Theory of constraints?

The primary objective of this project is to increase throughput, which means inventory has to be reduced and operating expenses decreased. The implication thereof is that if the product flow is reduced, operating expenses are decreased, inventory is decreased and throughput is increased.

The Theory of constraints is a good approach and solution technique to use in this project because; “TOC enables the firm to increase throughput while simultaneously reducing inventory and reducing operating expense” as stated by Aquilano et al (2009). Another important reason why the TOC approach is taken is because management is not in total control of the scheduling and supply of one of the primary resources (trains). The firm therefore only has total control on its internal supply operations; which requires assessment, evaluation and focus on local operational constraints that could be present in the system and therefore inhibiting the performance of the entire system; Elsevier (2009).

Once management has identified constraints and ways to alleviate constraints in order to improve productivity and system performance, they can then proceed to determine the new product loading schedule that is subordinated to the identified constraints, especially where operational resources are limited and conflicted.

Chapter 3

Model Description

The Arena model logic was based on the arrival of each individual client as a train arrival going through the process of hand in, loading and handover with the utilization of the necessary resources.

A separate process is modeled for each of the clients on each of the seven days because of the distinct time durations; tempos and product amounts (tons) loaded per client. Trains are handed in, loaded and handed over one at a time according to the sequence scheduled by Arena.

The model ensures the exact arrival of trains required by representing each client's arrival for each day in the required quantity. For each client scheduled for a specific day; a create module is built, referring the arrivals to a registered schedule for the number of trains arriving on that day of the week. Within the same create module, the maximum number of arrivals for that specific client for the respective weekday are specified.

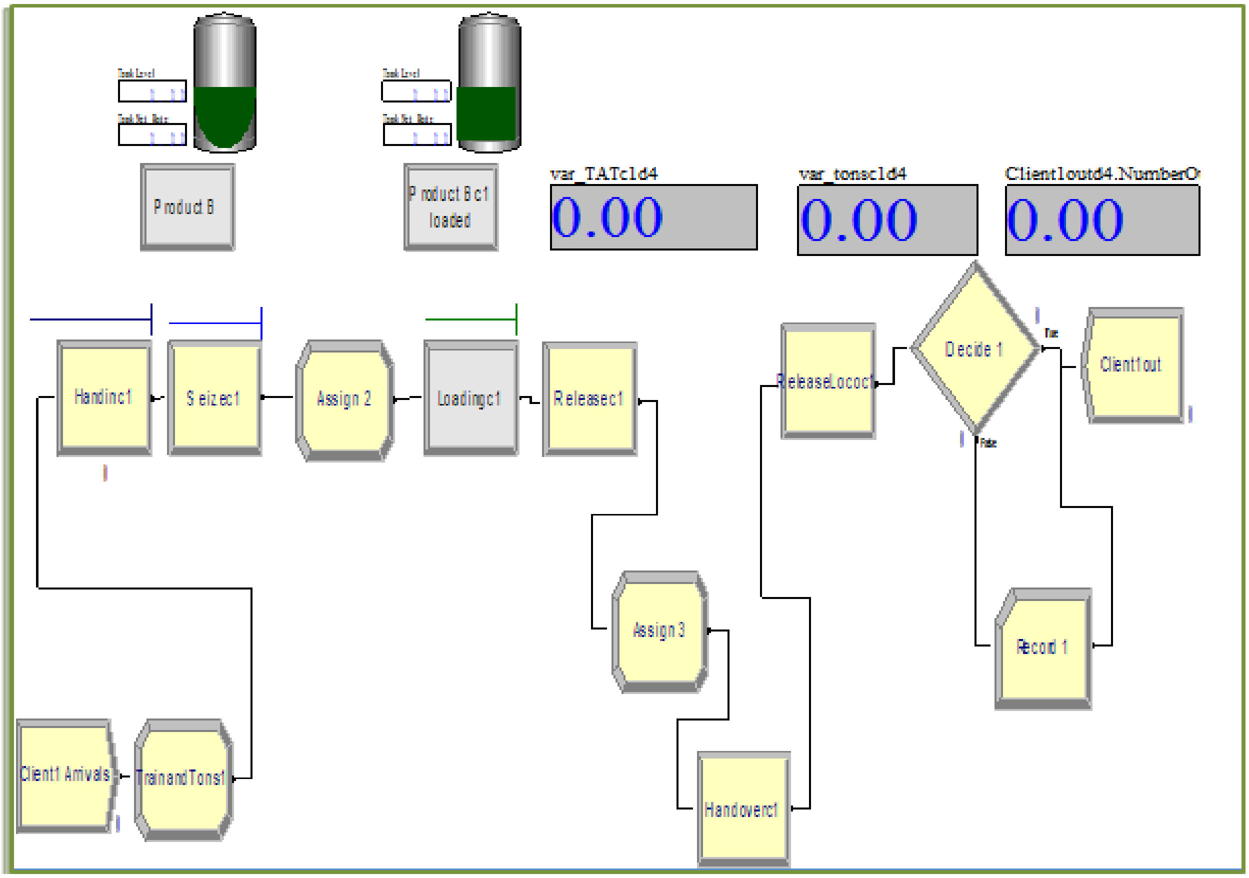
The processes followed after the arrival of each client are Hand-in, loading and handover; with the acquisition and releasing of the necessary resources as required by the process. For hand-in, the locomotive and rail loop need to be seized and for loading, the reclaimer, conveyor belts and load out station have to be seized.

Planned maintenance is modeled by reducing the capacity of the Load out station for the required amount of time (hours) by altering its availability during operation and during maintenance.

Refer to Appendix B for an overview of the model.

The following discussion describes the Arena model depicting train/client arrival, resource capacity, resource failures, handover times as well as maintenance.

Figure 3: Basic client loading model



3.1) Client Arrival Schedule

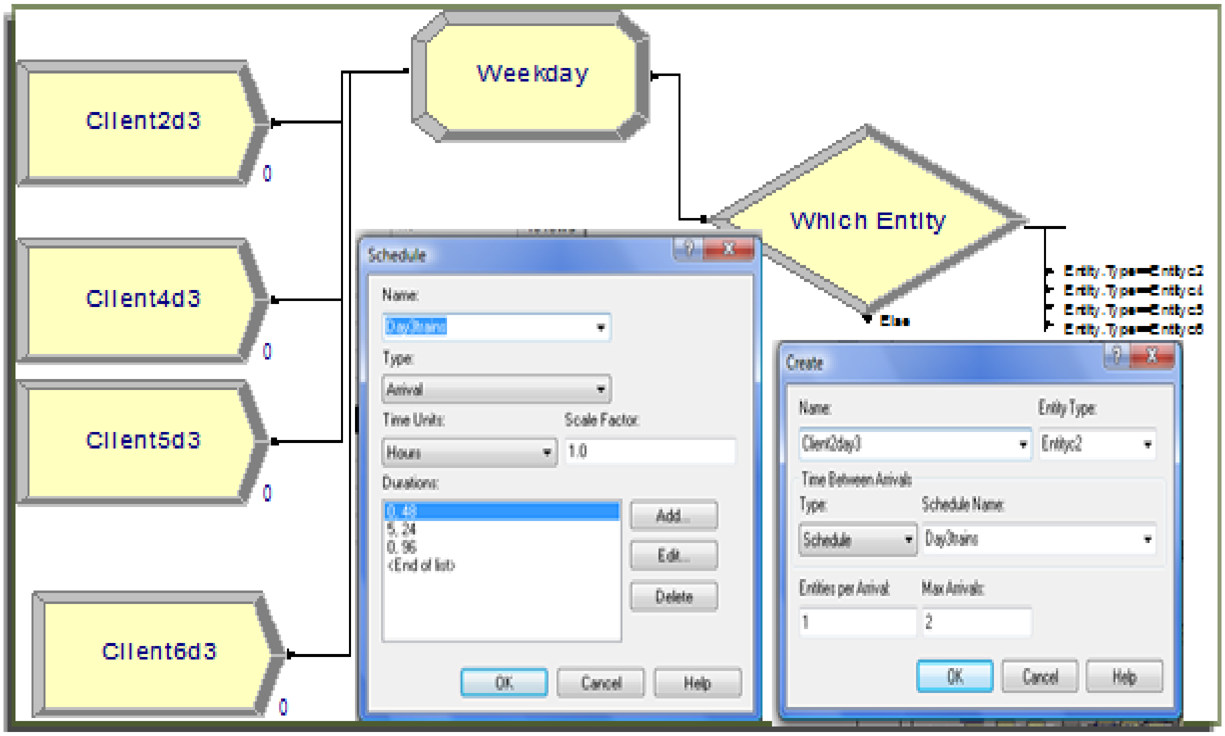
A 'Create' module is used to represent the arrival of a client for each of the seven week days in the quantity specified by the schedule. The client arrival also represents the train that was assigned for loading and consignment of the product. A client is registered as an entity type by the 'Create' module and recorded in the entity element as one of the system entities.

Before defining the entity arrival schedule using the 'Schedule' element, the Arrival type is registered as a schedule arrival in the 'Create' module. The 'Schedule' element assigns a certain amount of arrivals to certain duration of time. In this project, arrivals are registered on a daily basis which means durations to be used are 24 hour time periods. A schedule exists for each of the seven days which represents the maximum number of trains arriving that day and will be referenced in all the client arrivals/creations for that day.

Before the entity proceeds into the system, a 'Decide' module determines which entity type was assigned to the arrival in order to ensure that the right entity/client goes into the right process with all the input data specified for that client.

An 'Assign' module is used to register attributes and variables that are necessary to define and calculate the entity and entity activities as the entity proceeds through the system.

Figure 4: Basic client arrivals for day



3.2) Resource operations and failures

Resources are recorded in the model using the 'Resource' element; where the resource capacity is registered and the resource failures listed. The listed resources failures for all the resources involved in the project are then detailed in terms of the Up time (Mean Time between Failures) and Down time (Mean time till repair). The Failure type in the 'Failure' dialog box is registered as a time type of failure before the MTBF and MTTR are noted in the dialog box.

The MTBF depicts the probabilistic feature that the system/resource is operational before the interruption by unplanned system failures, interruptions or downtimes. The MTTR represents the probabilistic downtime due to unplanned failure before the resource is operational again. The MTBF and MTTR are represented as resource time operation concepts within the Failure module.

The modeling of the production or loading of product before loading is basically done in terms of the seizing and releasing of the necessary resources. It is then assumed that train loading from handover is synchronized with the conveyor loading process from the stockpiles due to the fact that handover times are relatively long which gives enough time to load a significant amount of product into the load out station; which makes the loading of coal from stockpiles to load out station a continuous process.

The sequence of the resource utilization is as follows for each loading period; the locomotive and rail loop are seized by the train for hand in and then follows the seizing of the Reclaimer, conveyor belts and load out station for loading. After loading of the product onto the train from the load out station, the conveyor belts, Reclaimer and load out station are released and only after handover can the rail loop and locomotive be released. The Reclaimer , normal conveyor, load out station conveyor and the load out station conveyor are seized for the consignment of client 1,2,3,4, and 6 whereas the resources used for client 5's loading process are the Product A conveyor, the load out station conveyor and the load out station.

3.3) Hand in

A 'Process' module is used to represent the Hand in process and the 'Seize Delay' logic within the 'Process' module is used to represent the utilization of resources as well as the time delay in the handover process prior to loading. The Uniform Distributions for the respective clients mentioned earlier in the report are then recorded to simulate the real world system hand over delay.

A variable is used to define the hand in time; the variable is assigned in the 'Assign' module before the Hand in process and registered in the 'delay type' field as an expression and then recorded in reference to the defined variable. The purpose of the use of variables to define hand in time delays is for ease animation of the handover times as well as to enable the calculation of TAT (Turn around times) later in the process after the loading and handover times have been defined and obtained from the model.

Train TAT times are obtained by adding the hand in times, loading times and handover times. For each day and each client in that day, variables are created to obtain the necessary information from the model regarding the client loading distributions. Some of the information traced and recorded are the TAT times for each client in that day, the number of trains loaded for each client in a specific time as well as the amount of product in tons dispatched to each client.

Variables representing TAT times and tons loaded for a specific day are assigned in such a way that they are added up (accumulated) for instances where more than one train is loaded per day for a specific client. E.g.
var_TATc5=var_TATc5+var_handinc5+var_loadingtimec5+var_handovertimec5.

3.4) Loading

Before the commencement of the loading process, a 'Seize' module is used to call on the resources needed to load the product from the stockpiles to the load out station. These resources entail the conveyor belts, Reclaimer and the load out station.

An 'Assign' module is the used to define a variable for the amount of product as well as the loading tempo. The definition of the variables is completed after the loading process with another 'Assign' module to calculate the TAT times and tons loaded per day for each client.

The 'Assign' modules prior to and after the loading process are also used to define the day of loading using the 'TNOW' variable. This is to assess whether loading is carried over to the next day. The 'Decide' module will then record instances where loading was carried over to the next day later in the process module.

Since the product flow is a continuous process; the 'Tank' and 'Flow' modules are used to denote the loading of product from the stockpiles to the Load out station. The 'Tank' module represents the respective stockpiles where capacity and flow rate of the product are recorded. In the 'Flow' module, the regulating source/Tank which represents a stockpile is recorded and the loading time denoted as the time after which the flow must be stopped. The flow destination then represents the loaded train ready for dispatch.

3.5) Handover and Dispatch

Final handover of trains takes place after train loading and the release of resources loading product from the stockpiles to the load out station (i.e. Reclaimer, conveyor belts and the load out station). At this stage, the loaded trains are handed over for dispatch with the rail loop and locomotive being utilized.

A 'Delay' module is used to denote the handover delay; with the uniform distribution handover time delays recorded in this module. After handover, the locomotive and rail loop are then released and made ready to be seized and utilized by the next client in the schedule. A 'Release' module is used in the model to denote the release of these resources.

After handover, a 'Decide' module is then used to evaluate whether the time prior to loading is equal to the time after loading, which will allow for the assessment of whether train loading was carried over to the next day. The variable used to define the days before and after loading should be fixed to ensure that the time recorded (i.e. TNOW) does not change as the model progresses.

Entities are directly disposed if loading is not carried over to the next day whereas the entities are recorded before disposal with the help of a 'Record' module if loading was carried over to the next day. The recording of entities with loading that was carried over to the next day will help in the identification of schedule constraints.

Although entities are carried over to the next day, the respective loading operation will be completed because the resources seized at the beginning of the process at hand in (Locomotive and rail loop) are only released at once hand over is complete at the end of the client loading operation. Therefore, carrying over of the loading process is a constraint on the system because there is a delay in the sequence for the next client to seize the necessary resources to proceed into the loading operation.

The basic modeling logic described above is followed for the modeling of the scheduling and arrivals of each of the six clients to be consigned. Refer to Appendix A for the functionalities and descriptions of the Arena modules/components mentioned above as well as to Appendix B for the entire model of all clients scheduled.

3.6) Maintenance

Planned downtime of the system basically entails the frequent maintenance of the load out station. This planned downtime is distinct from the MTTR as mentioned earlier in the report. The maintenance time is scheduled for every second Thursday between 7h00 and 16h00.

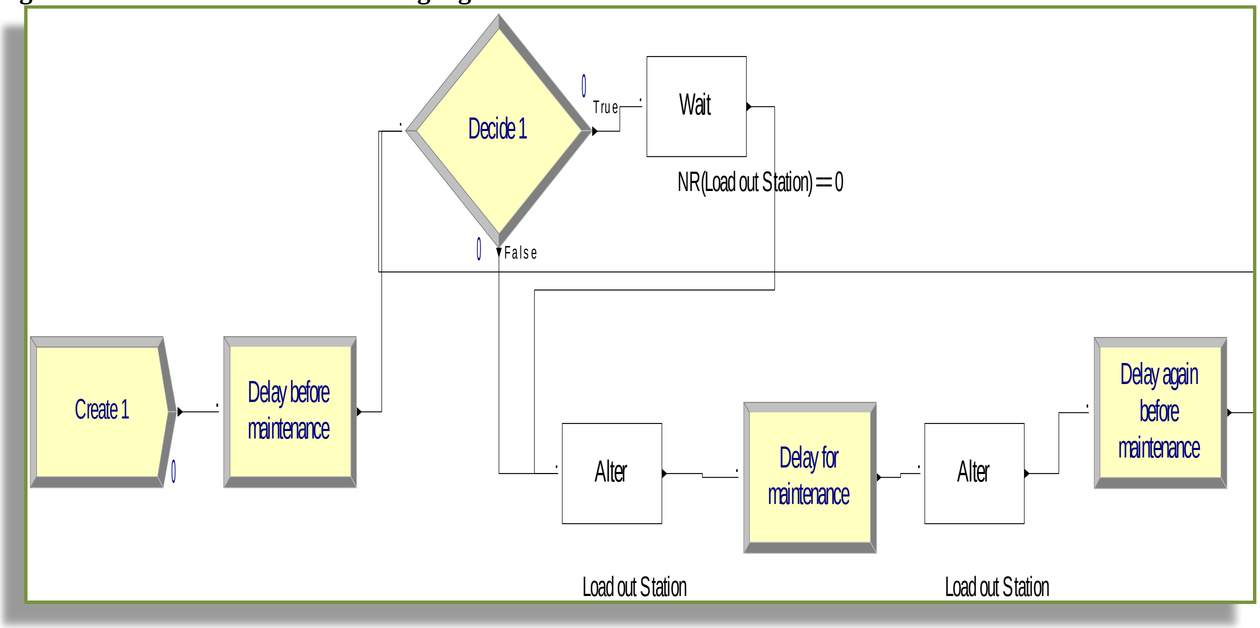
A separate occurrence of the maintenance activity is modeled with a constant arrival type Create module being used to denote the scheduled maintenance. Once the Maintenance arrival is created, a 'Delay' module is used to represent the amount of time the system is operational before maintenance takes place. Because this delay time is twelve days after the schedule proceeds (i.e. From Sunday 00h00 to the next Thursday 7h00), the amount of time registered in the delay module is 271 hours.

Before the load out station is made unavailable to maintenance, a 'Decide' module is used to determine whether the load out station is busy at the time scheduled for maintenance. If the load out station is not busy, the maintenance entity proceeds into the system to alter the availability (capacity) of the load out station to make it unavailable for maintenance. If the load out station is busy, on the other hand, the maintenance entity has to wait till the load out station is not busy before altering the load out station's capacity for maintenance.

An 'Alter' module is used to reverse the capacity of the load out station (i.e. make the load out station unavailable since it would then be due for maintenance). The capacity of the load out station within the 'Alter' block is changed to -1. An additional 'Delay' module is then used to represent the amount of time that the maintenance will be in progress; in this case it will be 9 hours since the system is down from 7h00 to 16h00.

An 'Alter' block will then be used again to redeem the capacity of the load out station resource, making it available again. A 'Delay' module will end off the maintenance process representing the number of hours again before another scheduled maintenance takes place the next second Thursday. The number of hours to represent the functional time of the load out station before another planned maintenance is found to be 327 hours (i.e. Thursday 16h00 till the Thursday in two weeks time at 7h00.) From that last 'Delay' module, the maintenance module will start to loop to the first 'Alter' block.

Figure 5: Planned downtime modeling logic



Chapter4

Input data and distributions

4.1) Empty Train arrival schedule

Train loading is based on a weekly schedule which is repeated and reviewed per annum. The schedule entails the arrival of trains as supplied by Transnet Freight Rail (TFR). Train supply is based on mainly on the company requirements which must be in line with the policies and regulations set by TFR. This project assumes that there is an infinite supply of trains to be loaded since improvements efforts are based on what the company itself can do to improve productivity and assure and efficient operation of the train arrival with the loading process. Table 1 represents the trains scheduled with the respective client and product to be loaded.

Table2: Client loading schedule

Day	Train Number	Nr of Trains/day	Product	Client
Sunday	101	2	Product A	Customer 5
	102		Product A	Customer 5
Monday	201	4	Product D	Customer 2
	202		Product A	Customer 5
	203		Product D	Customer 2
	204		Product C	Customer 3
Tuesday	301	5	Product D	Customer 2
	302		Product B	Customer 4
	303		Product A	Customer 5
	304		Product D	Customer 6
	305		Product D	Customer 2
Wednesday	401	5	Product D	Customer 2
	402		Product A	Customer 5
	403		Product D	Customer 2
	404		Product C	Customer 3
	405		Product B	Customer 1
Thursday	501	2	Product A	Customer 5
	502		Product B	Customer 4
Friday	601	5	Product D	Customer 2
	602		Product A	Customer 5
	603		Product D	Customer 6
	604		Product D	Customer 2
	605		Product B	Customer 1
Saturday	701	3	Product D	Customer 2
	702		Product A	Customer 5
	703		Product B	Customer 4

4.2) Loading

Loading takes place 24hours, 7 days a week. Loading commences everyday at 00h00. The specific client loading sequence or specific arrival times are not considered with regards to building the model since the project is mainly concerned with TAT times and productivity improvement by scheduling more trains. Another assumption made is that once a train is loaded, the next train in the sequence is available to be loaded. Planned maintenance of the Load out station is scheduled every second Thursday from 07h00 to 16h00, which means loading of trains will not be scheduled during that time.

4.3) Resources

The following is a discussion of the resources involved in the operation as well as their roles:

4.3.1) Load out station

The load out station is the train loading facility where trains stop to load product. The product is conveyed to the load out station from the respective stockpiles via conveyor belts, which makes it the primary resource in the project.

4.3.2) Reclaimer

The Reclaimer collects material from the stockpiles and loads it onto the Normal conveyor. The Reclaimer can only collect and load one product at a time. There is only one Reclaimer available for the entire process.

4.3.3) Load out station conveyor

The load out station conveyor loads the product from either the Product A conveyor or the Normal conveyor for direct loading of the product into the Load out station.

4.3.4) Product A conveyor

The Product A conveyor is responsible for the loading of product from the Product A stockpile (via the Reclaimer) to the Load out station conveyor.

4.3.5) Normal conveyor

The Normal conveyor loads product from stockpiles B, C and D for loading onto the Load out station conveyor. The conveyor will therefore load the product being reclaimed, which is the product to be loaded into the Load out station for consignment.

4.3.6) Locomotive

The locomotive is the train head used to pull the trains from the main railway line via the Rail loop to the Load out station and from the Load out station after loading to the main railway line.

4.3.7) Rail Loop

This is the railway facility that enables transportation of Product by train from the Load out station to the main railway line as well as the transportation of an empty train from the main railway line to the Load out station.

4.3.8) Mean Time between Failure (MTBF) and Mean Time till Repair (MTTR) Distributions

The following table represents the operational times of the resources as well as the probabilistic times of failure that will have a major impact on system performance.

Table3: MTBF and MTTR Distributions

FAILURES			Time Between Failures			Time to Repair		
Arena ID for Resources	Distribution	Unit	Best	Most Likely	Worst	Best	Most Likely	Worst
Reclaimer	Triangular	hr	60	45	30	1.25	1.88	2.50
Product A conveyor	Triangular	hr	60	45	30	1.25	1.88	2.50
Normal conveyor	Triangular	hr	60	45	30	1.25	1.88	2.50
Load out station conveyor	Triangular	hr	60	45	30	1.25	1.88	2.50
Locomotive (power trips)	Triangular	hr	60	45	30	1.25	1.88	2.50

4.9) Product Capacities and Annual volume targets

4.9.1) Product Capacities

The product capacities represent the capacities of the different product stockpiles. The startup level equal to the capacity represents the assumption that a product stockpile is continuously replenished. This assumption is based on the high reliability of production delivered to the stockpiles from the respective processing areas as well as the focus of productivity improvement efforts on the loading operations and train scheduling.

Table4: Product Capacities

Stockpile Levels (tons)		
Product	**Capacity**	**Start-up level**
Product A	60000	60000
Product B	45000	45000
Product C	40000	40000
Product D	58000	58000

4.9.2) Annual Volume Targets

The annual volume targets represent the minimum desired or budgeted production levels of each product per annum. The focus of this project is to reach the desired annual targets and exceed the throughput targets in efforts to improve productivity. Although the simulation model is only run over a month, the results obtained will be multiplied to annual figures to analyze whether the operations will deliver the desirable performance level.

Table5: Annual Product Volume targets

Customer	Annual Volume Targets (mil)	Tons
Customer 5	1.34	1 340 000
Customer 3	0.55	550 000
Customer 4	0.25	250 000
Customer 6	0.12	120 000
Customer 2	0.843	843 000
Customer 1	0.16	160 000

4.10) Client Loading and Distributions

The loading distributions for the Tons loaded per train (tons/train), the loading tempo as well as the loading duration are collected over an average period of 120 loading periods for each of the six clients.

The collected data for amount of tons loaded, loading durations and loading tempos vary in unique ways for each client for each day that the data is collected. Because the system behaves in a stochastic way, it is necessary to represent the data in a distribution that best describes the data probabilities and behaviors before using the selected distribution in the Arena model.

For the amount of tons and loading duration data collections, and analysis of the data was done using ‘East Fit’ in order to allocate the data to the best fitting distribution. Once installed, ‘Easy Fit’ is added into Excel as a function. The data to be analyzed is selected and then classified as either continuous or discrete before obtaining the distribution fits from the ‘Easy Fit’ function.

The continuous flow of product from the stockpiles to the conveyor belts, to the load out station justifies the classification of all client data as continuous. The solution obtained from the ‘Easy Fit’ function comprises the available distribution fits with their respective graphs that allow the user to obtain a visual of how the distribution fits the data.

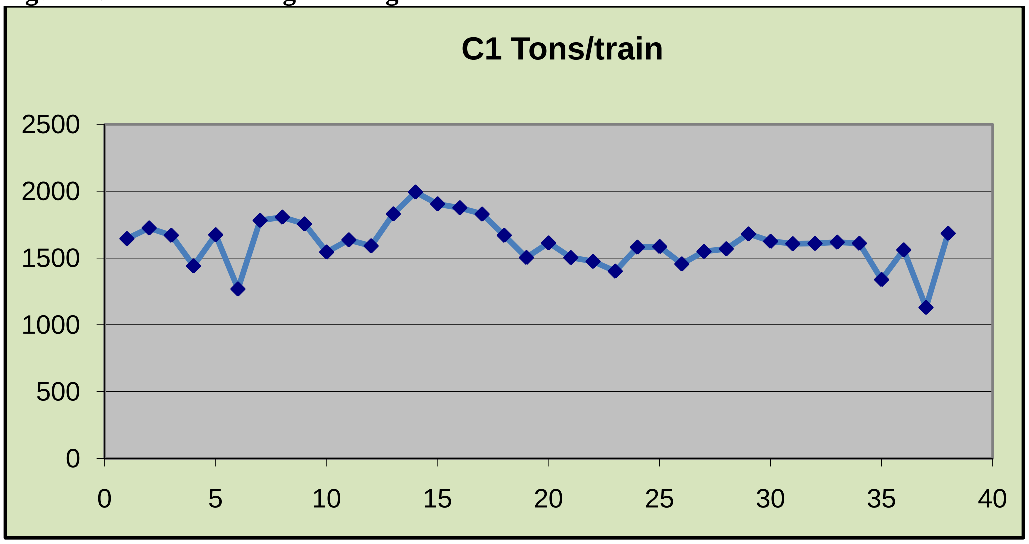
The ‘Goodness of fit’ test, which is also in the solution, ranks the distributions according to which suits the data better, The rankings are done based on definitions of the Distribution types by Kolmogorov Smirnov and Anderson Darling. Refer to Appendix C for an overview of how the ‘Easy Fit’ application works. The data collected is presented in the form of graphs and the respective distributions discussed in the following figures.

The data being analyzed is the distributions for the amount of product (tons) loaded for each client as well as the respective duration for the loading of product. This is done to ensure that Arena models the tonnage loading according to the pattern of the data distribution as collected for the actual process. Some of the data samples are quite small due to time and information constraints. No distribution fit is required for the Loading Tempo data because Arena only requires the maximum flow rate/tempo (tons/min) for registration in the Product Tank (stockpile) regulator.

4.10.1) Client 1

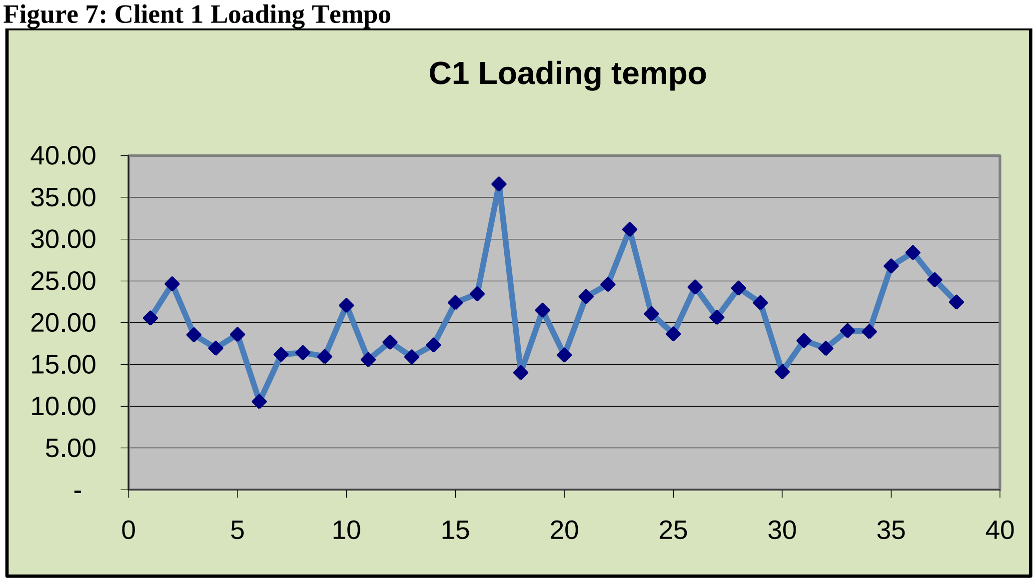
Data collected for client 1 represents the loading and consignment of Product B over a period of 41 Loading periods.

Figure 6: Client 1 Tonnage loading



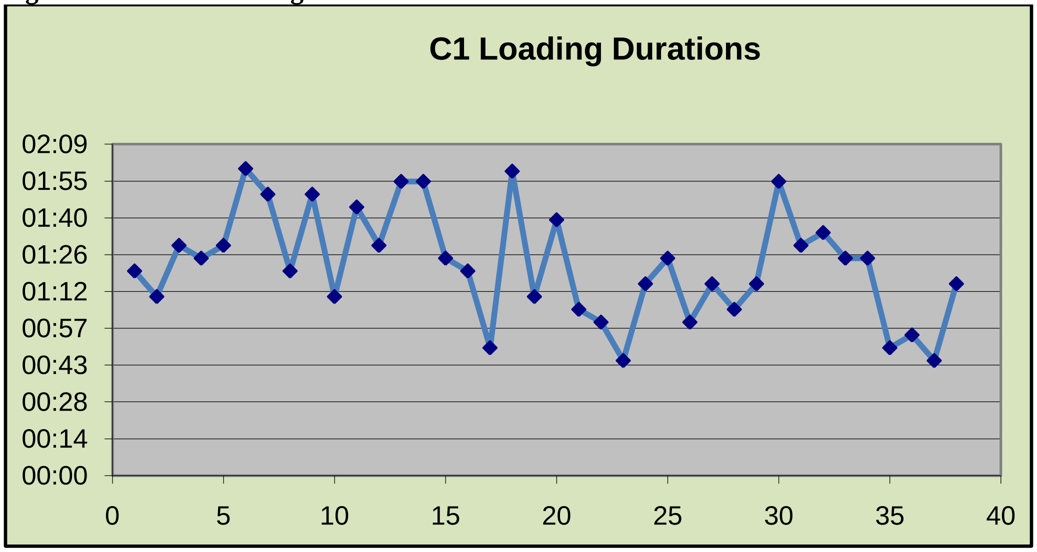
The selected distribution from the 'Easy Fit' function is the Johnson SB distribution. The distribution is represented by the Gamma, Delta, Lambda and xi parameters for the probability distributions as: γ= 0.0523, δ=0.66875, λ=43.365, ξ=-0.53144

Figure 7: Client 1 Loading Tempo



The required maximum rate/loading tempo (tons/min) for client 1 is 37 tons/min.

Figure 8: Client 1 Loading Durations

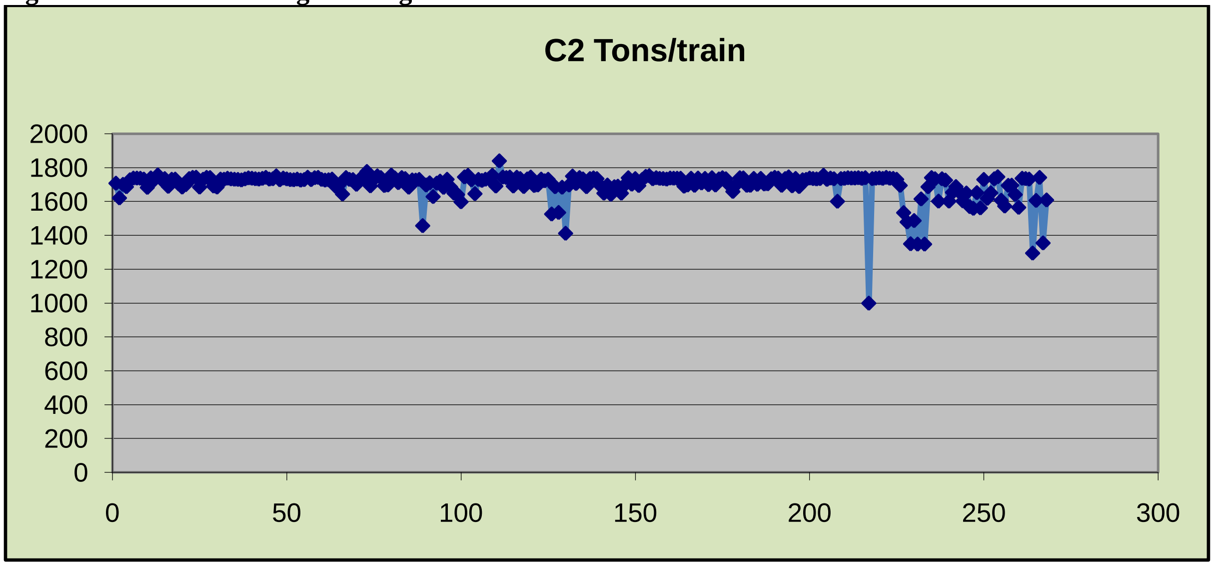


The selected distribution from the 'Easy Fit' function is the Normal distribution. The standard deviation and mean parameters representing the distribution are: μ= 01:44 and σ= 0.079432709.

4.10.2) Client 2

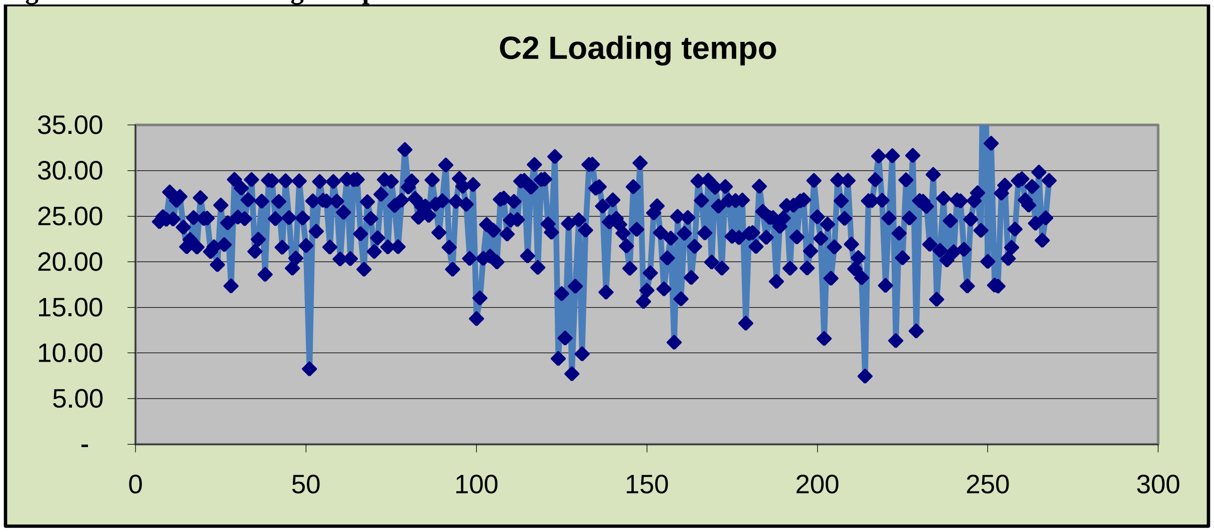
Data collected for client 2 represents the loading and consignment of Product D over a period of 268 loading periods.

Figure 10: Client 2 Tonnage loading



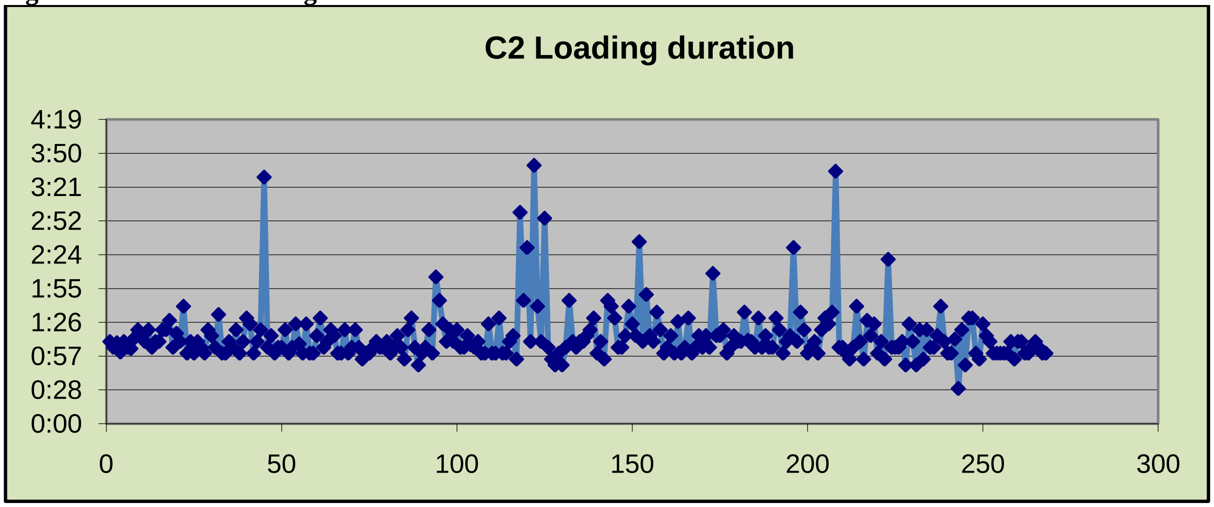
The selected distribution from the 'Easy Fit' function is the Uniform distribution. The maximum and minimum parameters representing the distribution are: Min= 998 and Max= 1840.

Figure 9: Client 2 Loading Tempo



The required maximum rate/loading tempo (tons/min) for client 2 is 33 tons/min.

Figure 11: Client 2 Loading Durations

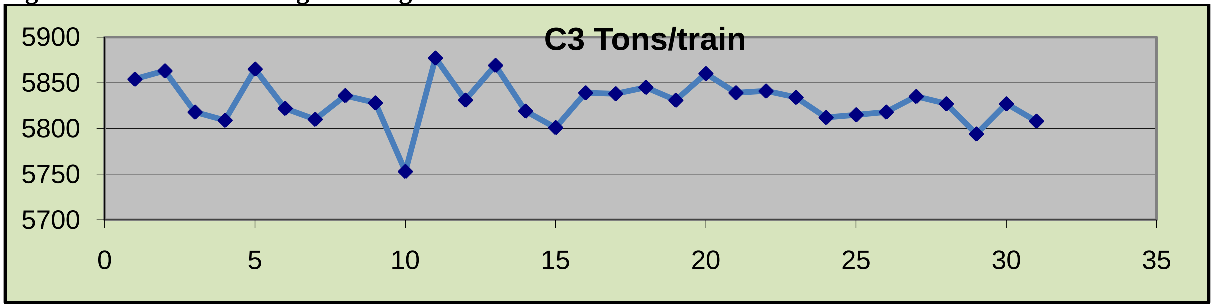


The selected distribution from the 'Easy Fit' function is the Johnson SB distribution. The distribution is represented by the Gamma, Delta, Lambda and xi parameters for the probability distributions as: γ= -0.01922, δ=0.60405, λ=285.51, ξ=-10.021

4.10.3) Client 3

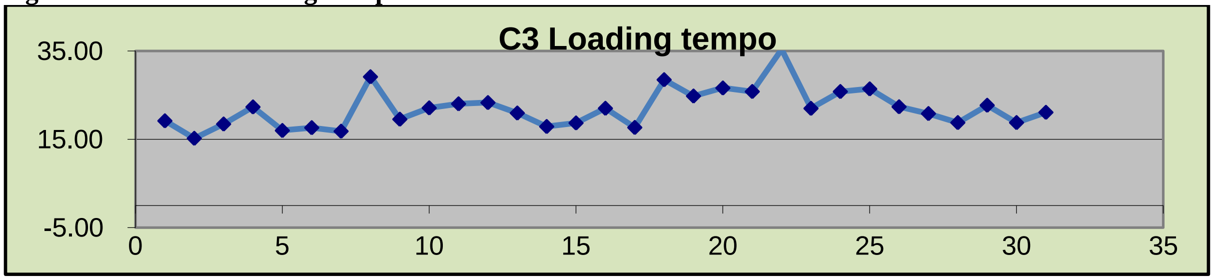
Data collected for client 3 represents the loading and consignment of Product C over a period of 31 loading periods.

Figure 12: Client 3 Tonnage loading



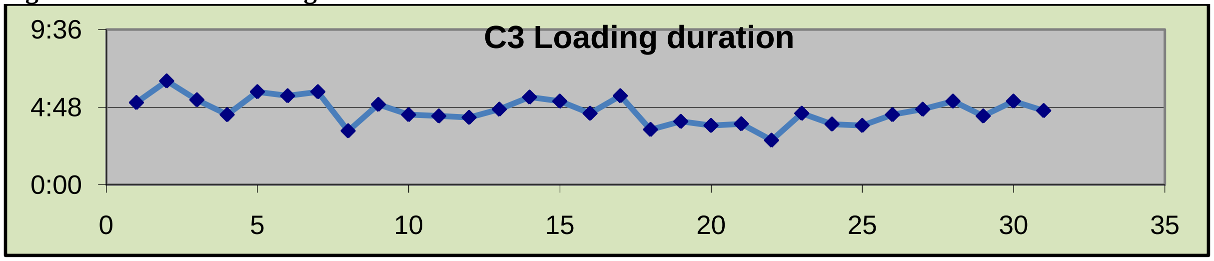
The selected distribution from the 'Easy Fit' function is the Uniform distribution. The maximum and minimum parameters representing the distribution are: Min= 5750 and Max= 5880.

Figure 13: Client 3 Loading Tempo



The required maximum rate/loading tempo (tons/min) for client 3 is 36 tons/min.

Figure 14: Client 3 Loading Durations

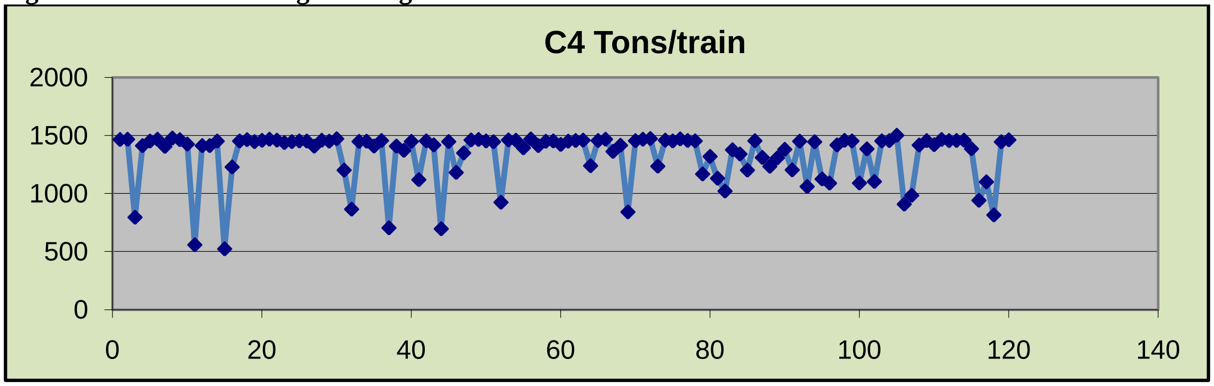


The selected distribution from the 'Easy Fit' function is the Johnson SB distribution. The distribution is represented by the Gamma, Delta, Lambda and xi parameters for the probability distributions as: γ= 0.10654, δ=0.60049, λ=32.138, ξ=-0.24748

4.10.4) Client 4

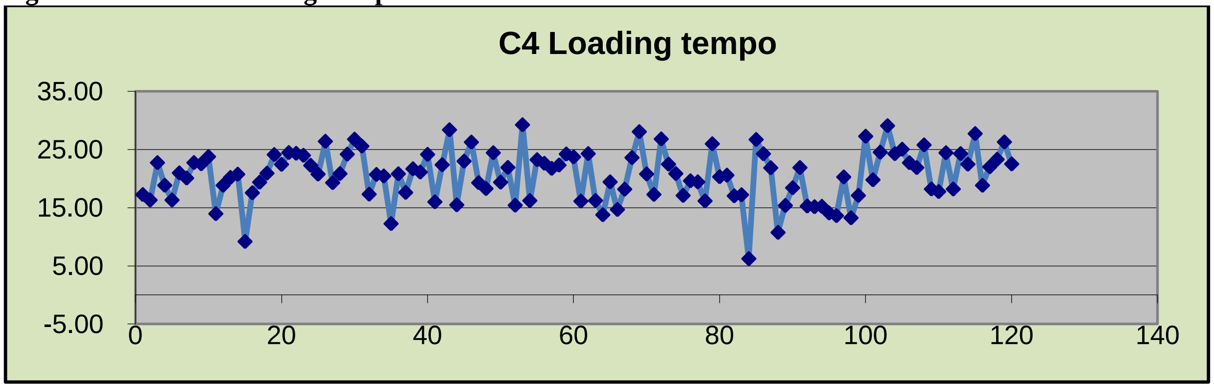
Data collected for client 4 represents the loading and consignment of Product B over a period of 121 loading periods.

Figure 15: Client 4 Tonnage loading



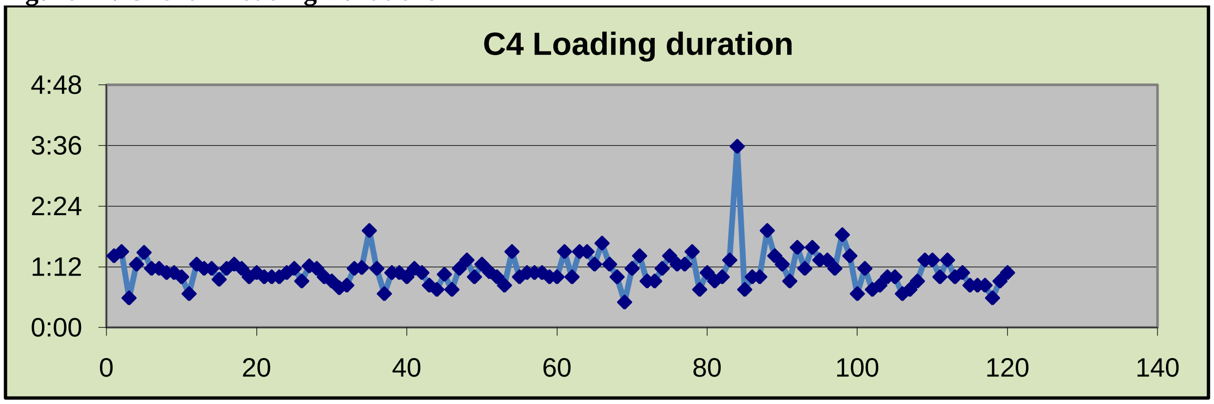
The selected distribution from the 'Easy Fit' function is the Beta distribution. The alpha1 and alpha2 parameters representing the distribution are: α_1= 98705 and α_2= 0.9985.

Figure 16: Client 4 Loading Tempo



The required maximum rate/loading tempo (tons/min) for client 4 is 30 tons/min.

Figure 17: Client 4 Loading Durations

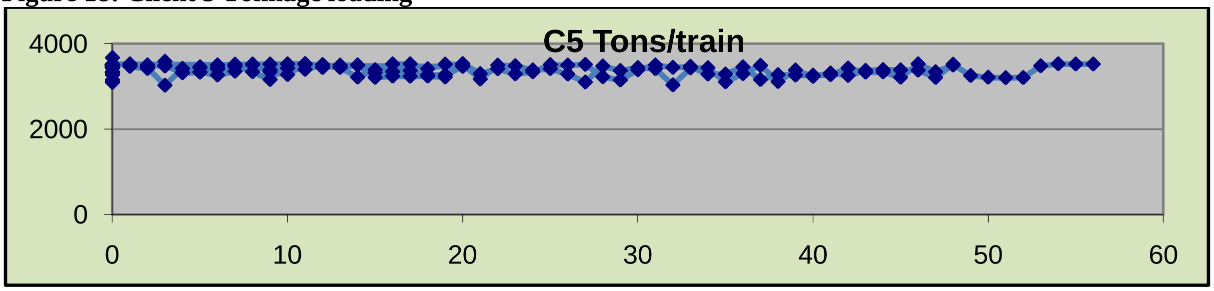


The selected distribution from the 'Easy Fit' function is the Johnson SB distribution. The distribution is represented by the Gamma, Delta, Lambda and xi parameters for the probability distributions as: γ=-0.07484, δ=0.66855, λ=126.09, ξ=-4.8879

4.10.5) Client 5

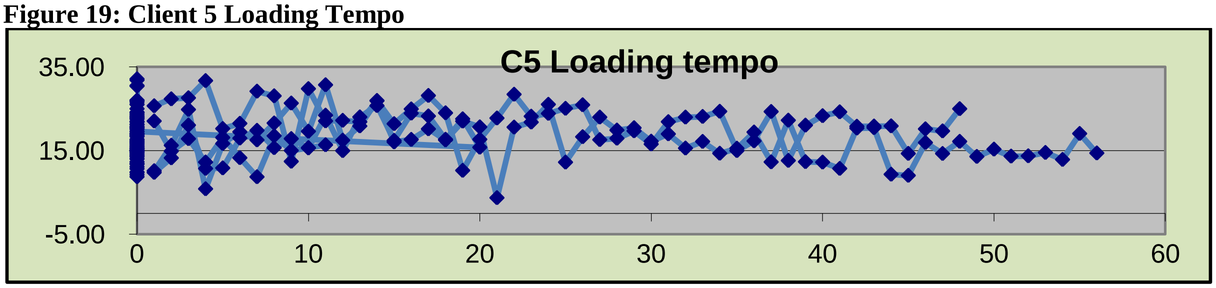
Data collected for client 5 represents the loading and consignment of Product A over a period of 231 loading periods.

Figure 18: Client 5 Tonnage loading



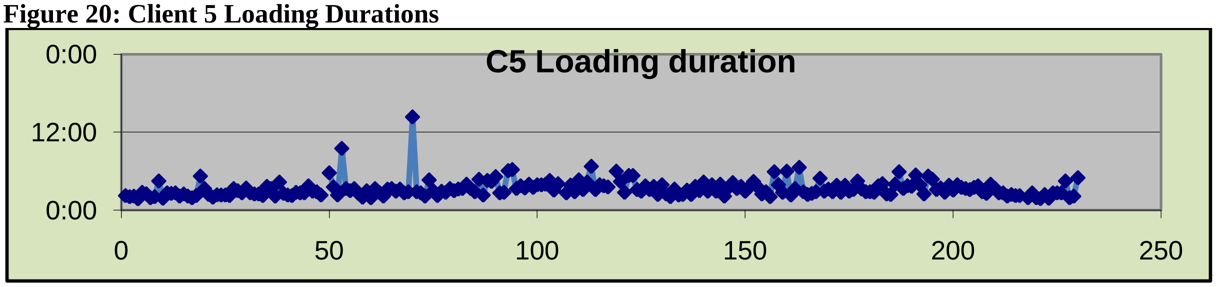
The selected distribution from the 'Easy Fit' function is the Uniform distribution. The maximum and minimum parameters representing the distribution are: Min= 3020 and Max= 3670.

Figure 19: Client 5 Loading Tempo



The required maximum rate/loading tempo (tons/min) for client 5 is 33 tons/min.

Figure 20: Client 5 Loading Durations

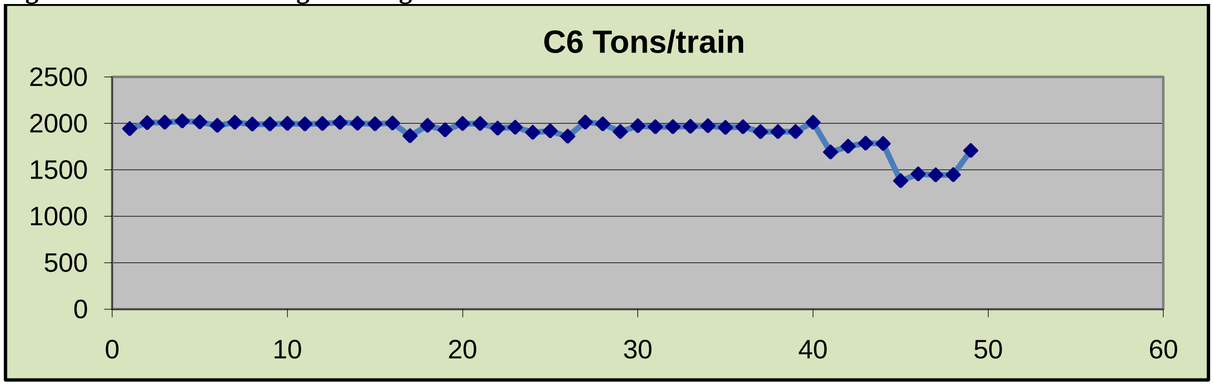


The selected distribution from the 'Easy Fit' function is the Johnson SB distribution. The distribution is represented by the Gamma, Delta, Lambda and xi parameters for the probability distributions as: γ=-0.07875, δ=0.62591, λ=58.988, ξ=-1.8339

4.10.6) Client 6

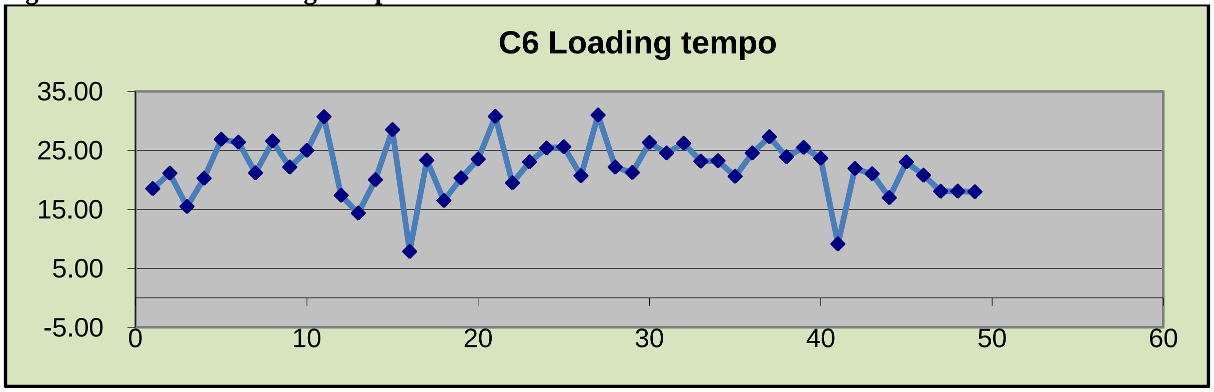
Data collected for client 6 represents the loading and consignment of Product D over a period of 49 loading.

Figure 21: Client 6 Tonnage loading



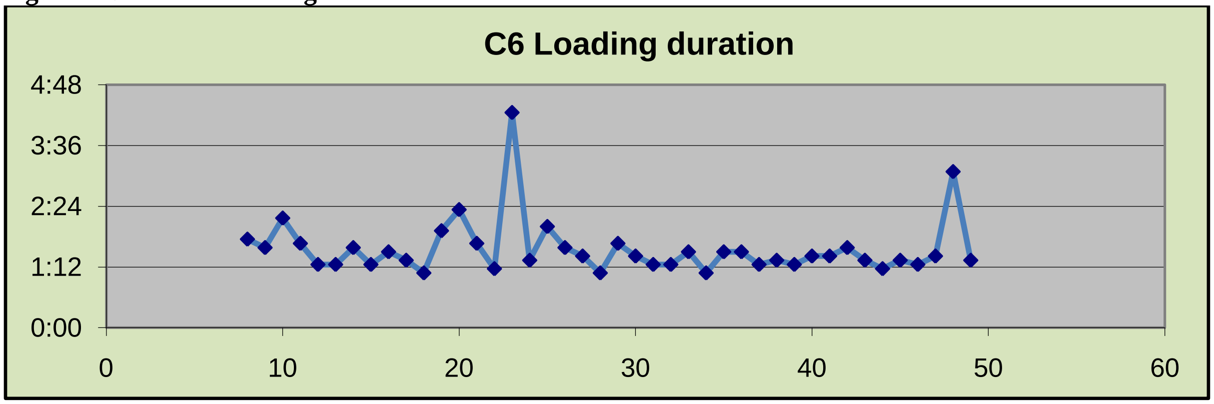
The selected distribution from the 'Easy Fit' function is the Power Function distribution. The distribution is represented by the Alpha, Maximum and Minimum parameters for the probability distributions as: α=-0.93411, Min=1380, Max=2030 (tons)

Figure 22: Client 6 Loading Tempo



The required maximum rate/loading tempo (tons/min) for client 6 is 31 tons/min.

Figure 23: Client 6 Loading Durations



The selected distribution from the 'Easy Fit' function is the Power Function distribution. The distribution is represented by the Alpha, Maximum and Minimum parameters for the probability distributions as: α=-0.93607, Min=65, Max=122 (minutes)

Although 'Easy Fit' aids in obtaining the best fit to a distribution of data, it is essential that the correct parameters are used and expressed correctly in the Arena model. In order to obtain the correct expressions of the data distributions and their parameters, the Arena input analyzer is used to obtain the correct expressions for the model.

The data is analyzed from a text file by the input analyzer which returns a histogram, data expression and expression of the data for the selected distribution. The input analyzer also has the capability to fit the best distribution to the data, which would serve as a validation to the distribution selected from 'Easy fit'. Refer to Appendix E for an example of the input analyzer functionality.

4.11) Handover Time Delays

Handover time represents the time spent receiving the train from the main railway line along the Rail loop to the Load out station. The following table represents the respective client handover delays:

Table 6: Handover time distributions

Hand Over Delays		min	max
Customer 1	hr	1	2
Customer 2	hr	1	2
Customer 3	hr	1.5	2.45
Customer 4	hr	1	2
Customer 5	hr	1	2
Customer 6	hr	1	2

Chapter5

Model Validation and verification

The evaluation of whether the software is performing according to the specified system as well as the comparison of model results under current operating conditions with the real system performance will help provide confidence in the model as well as ensure that model assumptions are complete and correct. The model validation was done in terms of the trains that go into the system and the trains that go out for each customer per day. Tons delivered from each client loading are calculated per week in order to assess whether the product delivered per week at least reaches the minimum tonnage loading of each client per week. Handover times as well as loading times are also assessed according to the minimum and maximum times in the distributions for each client. The general validation of the model was done on the weekly schedule and thus on the model run for one week. Effects of the maintenance schedule are thus not taking into consideration during validation of the model since the maintenance is currently being done every second Thursday.

5.1) Train input and output

Figure 24: Arena report of entity

	Number In	Number Out
Entity maint	1	0
Entityc1	2	2
Entityc2	9	9
Entityc3	2	2
Entityc4	3	3
Entityc5	8	8
Entityc6	2	2
Total	27	26

The input and output report from Arena reflects that the model delivers the required input and output of train arrivals per week.

5.2) Tons loaded

A validation was also done on the amount of product loaded for the trains for each client.

Comparison was made to the loading distribution for each client each day.

Table 7: Validation of model results for tons loaded

Actual	TRIA(1340,1610,1990)	TRIA(1460,1730,1840)		TRIA(5750,5820,5880)
	Client1	**Client 2**		**Client3**
	Arena (tons)	*Arena(tons)*		*Arena(tons)*
Day1				
Day2		1553.13	1629.67	5804.12
Day3		1700.14	1796.89	
Day4	1867.69	1629.57	3303.4	5824.57
Day5				
Day6	1916.49	1705.79	1661.63	
Day7		1792.91		
Actual	**TRIA(908,1470,1500)**	**TRIA(3200,3490,3670)**		**TRIA(1710,2000,2030)**
	Client 4	**Client5**		**Client6**
	Arena(tons)	*Arena(tons)*		*Arena(tons)*
Day1		3385.39	3530.27	
Day2		3576.45		
Day3	1139.13	3437.89		1827.1
Day4		3649.76		
Day5	1258.79	3336.73		
Day6		3530.06		1981.25
Day7	1435.55	3446.21		

5.3) Loading times

Validation of the model with regards to loading times is as follows:

Table 8: Validation of Model results for loading time

Actual	TRIA(53,96,134)	TRIA(56,64,132)		TRIA(163,273,383)
	Client1	**Client 2**		**Client3**
	Arena (min)	*Arena(min)*		*Arena(min)*
Day1				
Day2		72.73	93.8	290.6
Day3		86.08	124.71	
Day4	56.28	78.54	92.24	292.59
Day5				
Day6	120.27	96.19	67.55	

Day7		**73.05**		
Actual	**TRIA(50,65,90)**	**TRIA(111,165,291)**		**TRIA(65,87,122)**
	Client 4	**Client5**		**Client6**
	Arena(min)	***Arena(min)***		***Arena(min)***
Day1		**218.65**	**202.2**	
Day2		**164.79**		
Day3	**72.49**	**135.97**		**67.09**
Day4		**140.45**		
Day5	**77.08**	**274.78**		
Day6		**176.75**		**89.38**
Day7	**78.62**	**166.28**		

5.4) Handover Times

It is important to ensure that correct handover times are delivered by the model because these times, along with loading times make up the TAT times; which will play a primary role in the formulation of improvement scenarios and TOC analyses during experimentation and analysis of the model.

Table 9: Validation of Model results for handover times

Actual	**UNIF(1,2)**	**UNIF(1,2)**		**UNIF(1.45,2.45)**	**UNIF(1,2)**	**UNIF(1,2)**		**UNIF(1,2)**
	Client1	**Client 2**		**Client3**	**Client 4**	**Client5**		**Client6**
	Hand-in: Arena(hours)							
Day1						**1**	**1.02**	
Day2		**1.67**	**1.67**	**1.79**		**2**		
Day3		**1.31**	**1.31**		**1.36**	**1.3**		**1.01**
Day4	**1.28**	**1.82**	**1.82**	**1.67**		**1.9**		
Day5					**1.46**	**1.5**		
Day6	**1.2**	**1.15**	**1.15**			**1.2**		**1.78**
Day7		**1.5**			**1.43**	**1.1**		
	Client1	**Client 2**		**Client3**	**Client 4**	**Client5**		**Client6**
	Handover: Arena(hours)							
Day1						**1.4**	**1.16**	
Day2		**1.95**	**1.94**	**2.07**		**1.6**		
Day3		**1.96**	**1.39**		**1.23**	**1.9**		**1.42**
Day4	**1.3**	**1.37**	**1.33**	**1.46**		**1.2**		
Day5					**1.95**	**1.9**		
Day6	**1.03**	**1.19**	**1.36**			**1.3**		**1.83**
Day7		**2**			**1.85**	**1.8**		

From the model results and actual data above, it is evident that the model performs within specifications. The Confidence gained in the model performance form the model validation therefore allows proceedings to the model Experimentation and analysis.

Chapter 6

Experimentation and Analysis

6.1) Current Scenario

6.1.1) Monthly performance overview

An overview of the current system is analysed by running the Arena model for a month. This is to assess whether the system would perform within the required annual budget. In order to get an idea of whether the system is delivering the required monthly target, the annual budget volumes of product for each client mentioned earlier in the report are divided by twelve to get a monthly estimate of the respective product budget. The production is then represented to evaluate whether production for the month reaches the monthly target (budget) for each product and client. The analysis will help later in the project to evaluate whether the removal of constraints and addition of trains according to the respective improvement scenarios are effective.

The following diagrams represent the cumulative monthly performance in terms of throughput for each client. The times for the graphs differ for each client due to the fact that loading and consignment of the clients as depicted in the schedule differ (some clients are loaded more often than others during the month). Refer to Appendix D for a detailed overview of the monthly performance data from the Arena model.

Figure 25: Client 1 monthly performance overview

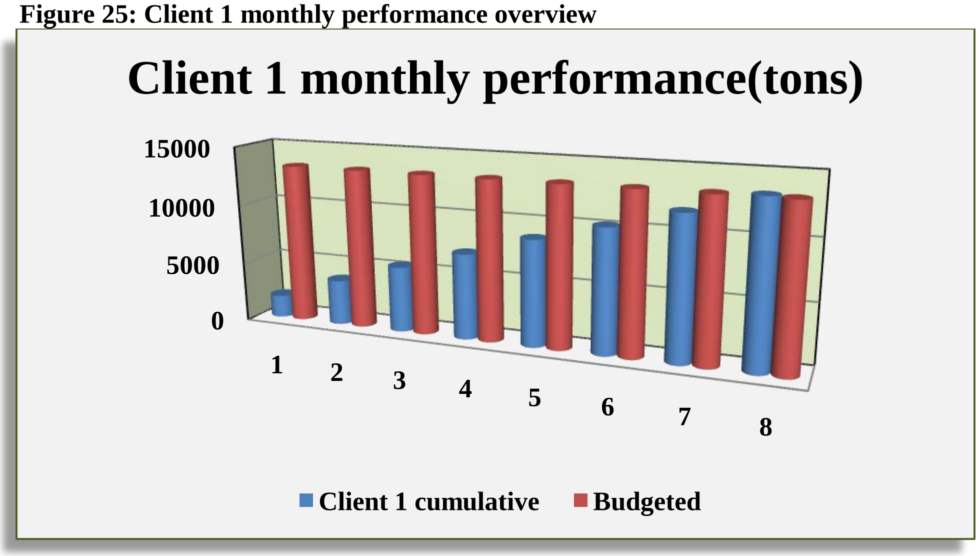


Figure 26: Client 2 monthly performance overview

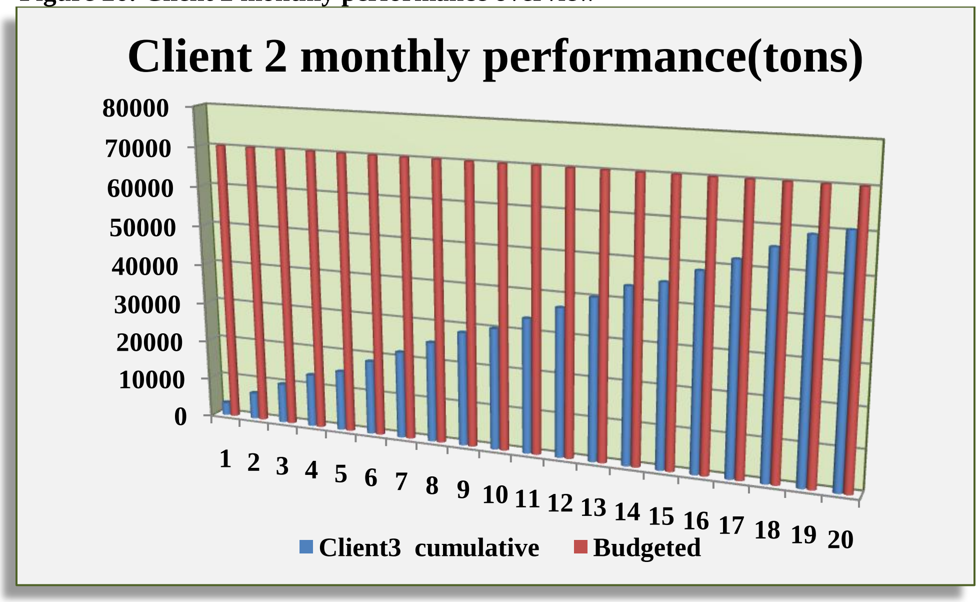


Figure 27: Client 3 monthly performance overview

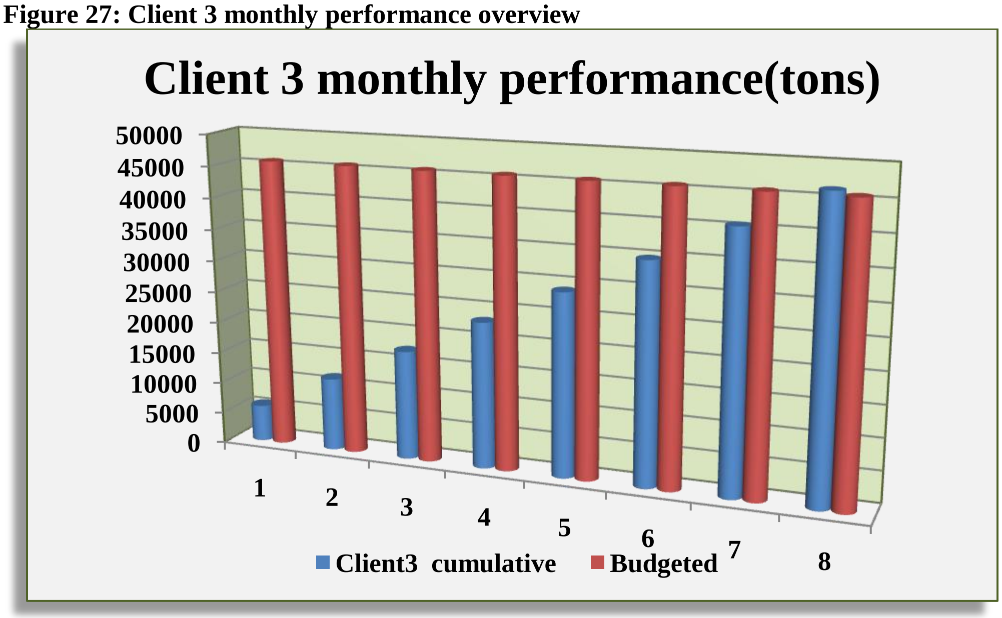


Figure 28: Client 4 monthly performance overview

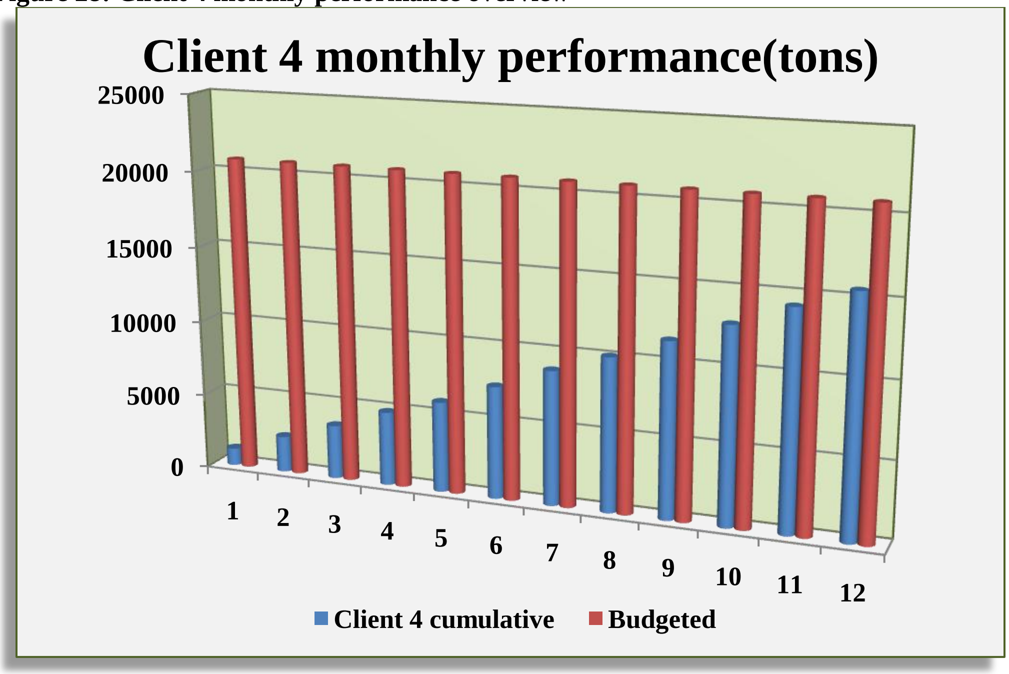


Figure 29: Client 5 monthly performance overview

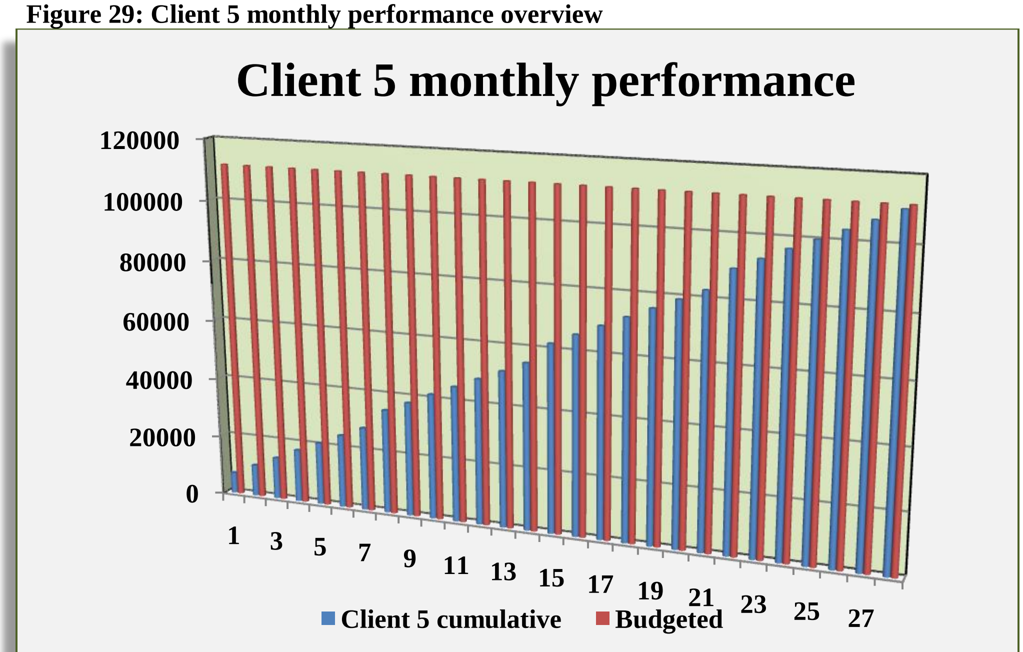


Figure 30: Client 6 monthly performance overview

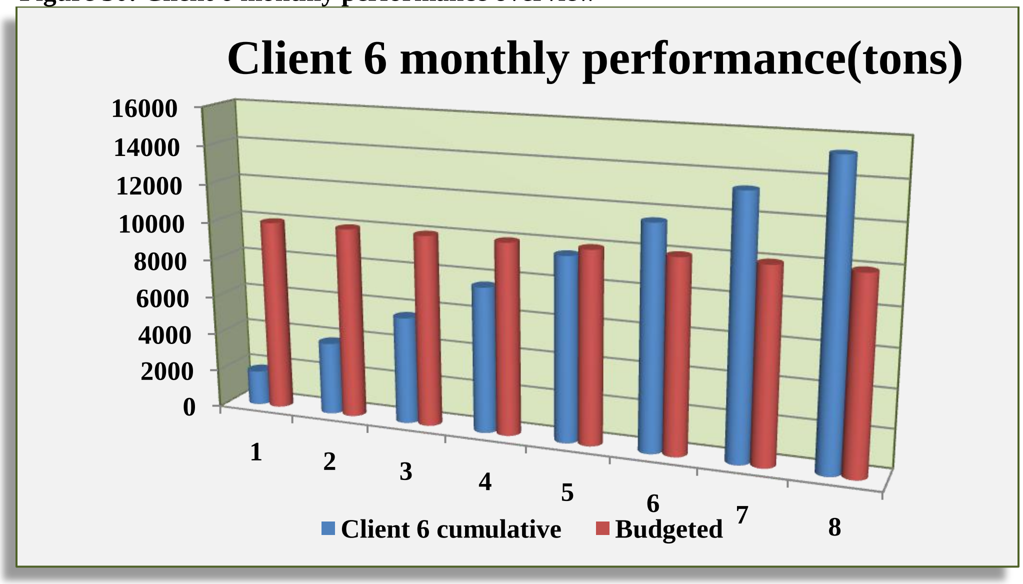


Table 10: Comparison of actual product versus budgeted volume

Monthly total	*Client1*	*Client2*	*Client3*	*Client4*	*Client5*	*Client6*
Actual(model)	13446	60657	46538	15596	110378	15310
Budgeted	13333	70250	45833	20833	111666	10000

As seen from the graphs and table above; client1, 3 and 6 product consignment meet the required/budgeted value of throughput whereas client2, 4 and 5 do not deliver the budgeted product volumes. In the formulation of improvement scenarios (constraint elimination, overutilization elimination and re-scheduling), attention should be given to increasing the trains loaded for the underperforming clients' product consignment.

6.1.2) Utilization Analysis

Before experimentation with the increase in number of trains can be done on the system, a Utilization analysis is done on the current operation scenario (schedule) to identify and eliminate any scheduling constraints for each day. The analysis is done by comparing the daily time demand of the scheduled customers per day to the available time (24 hours) in a day. Opportunities to schedule additional trains are also seen from the under-utilization of available operational time per day for the client arrivals scheduled. The analysis is done by obtaining average TAT times for each day from TAT time results from ten replications of the model. The utilization analysis is done on the running of the model for one week which means the planned maintenance (takes place every second Thursday) effects will not be taken into consideration.

Due to the fact that the planned maintenance could have an impact on the schedule, the daily capacity on Thursdays (Day 5) is reduced to 15 hours to accommodate the time required for planned maintenance (9 hours).The following table represents the utilization analysis done on the current schedule and operation scenario:

Table 11: Utilization analysis on time capacities

Replications	*Day 1*	*Day 2*	*Day3*	*Day 4*	*Day 5*	*Day 6*	*Day 7*
	TAT time (hours)						
Rep 1	**11.63**	**24.99**	**22.29**	**26.11**	**12.61**	**22.33**	**14.76**
Rep 2	**11.9**	**24.31**	**23.76**	**27.18**	**9.58**	**24.74**	**13.86**
Rep 3	**13.06**	**22.41**	**25.73**	**25.88**	**10.3**	**23.63**	**15.47**
Rep 4	**12.77**	**22.13**	**24.11**	**28.97**	**10.3**	**24.53**	**13.93**
Rep 5	**10.43**	**24.17**	**26.55**	**25.07**	**10.64**	**24.26**	**16.14**
Rep 6	**9.48**	**22.99**	**23.57**	**29.37**	**8.69**	**24.81**	**14.24**
Rep 7	**13.86**	**24.14**	**26**	**26.23**	**11.44**	**23.89**	**14.73**
Rep 8	**12.61**	**23.8**	**24.01**	**30.43**	**11.5**	**25.64**	**13.32**
Rep 9	**11.47**	**23.41**	**22.35**	**27.26**	**11.92**	**24.41**	**15.09**
Rep 10	**13.09**	**22.94**	**24.39**	**26.58**	**10.02**	**24.6**	**14.4**
Average Demand	**12.03**	**23.529**	**24.276**	**27.308**	**10.7**	**24.284**	**14.594**
Capacity	**24 hours**				**15 hours**	**24 hours**	

From the utilization analysis above, the major schedule constraints (over-utilization of time capacity) are identified as Day3, Day4 and Day 6 and Day. In order to exploit these system constraints, there has to be rescheduling of the client arrivals for those days according to the prioritisation of the client supply as well as the product need for each client every week.

The addition of trains after rescheduling will therefore be subordinated to the constraint areas after the identification and exploitation of the over-utilization areas. Elevation of the identified constraints will entail the re-scheduling of client arrivals that were removed from a certain day to another day in order to make up for the lost capacity of throughput from elimination of over-utilization.

6.1.3) Formulation of improvement scenarios

The formulation of improvement scenarios basically entails the elimination/exploitation of over-utilized TAT times by reducing the TAT time where TAT time exceeds the available time per day (24hours). Another element of the system improvement as mentioned in the project aim is the additional scheduling of more trains according to the amount of time remaining to accommodate additional TAT times per day.

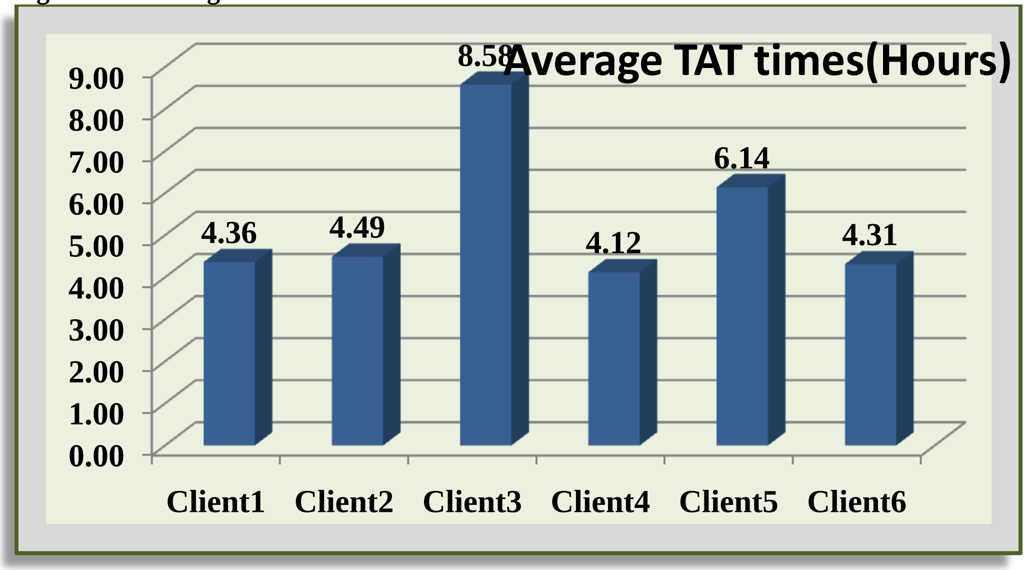
6.1.3.1) Improvement formulation methodology

- Identify over-utilization in the schedule (TAT time exceeds available time) (Day3, 4 and 6)
- Identify under utilization in the schedule (excess/remaining TAT times not used)
- Calculate the average TAT time of each client from the running of the schedule for 5 weeks (approximately one month)
- From the average TAT times calculated, decide which client can be removed from the schedule of that specific constrained day. (Least TAT time client can be removed)
- Schedule additional trains to days in the schedule where there is an under-utilization of the available time.
- Improvement Scenario1- Addition of trains
- Analysis of Scenario 1 (Utilization analysis, efficient operation and increased throughput)
- Formulate scenario 2 (Constraint elimination depending on analysis and results obtained in scenario 1)
- Evaluation of improvement scenarios.

6.1.3.2) Calculation of average TAT times

Since constraints and under-utilization areas in the schedule have already been identified (Figure 29), it is now necessary to calculate the average TAT times of the clients from running the model for five weeks in order to enable the formulation of improvement scenarios as mentioned in the improvement methodology. The following table represents the calculation of average TAT times from running the model for a period of 5weeks. Refer to Appendix F for a detailed overview of the Average TAT time calculations.

Figure 31: Average TAT times



6.2) Improvement Scenario 1

Improvement scenario 1 is formulated according to the improvement formulation methodology discussed above. Over-utilization will be eliminated to reduce weight off the system bottleneck according to the Utilization analysis; clients not satisfactorily consigned according to the monthly volumes required should be brought to reconciliation by scheduling additional trains where there is unutilized time available in the schedule.

6.2.1) Elimination of over-utilization

The elimination of the system constraints is done from the Utilization analysis where day 4 was identified as the main over-utilization area in the train arrival and loading schedule. Client1 is removed from the schedule on day 4 and moved to day 5 where there is an average of 5 hours TAT available; this is fitting to the schedule because the average TAT time for client 1 as shown in Figure 29 is 4.36 hours.

Table 12: Elimination of over-utilization

Removal of constraints	***Day 1***	***Day 2***	***Day3***	***Day 4***	***Day 5***	***Day 6***	***Day 7***
	TAT time (hours)						
Average Demand	**12.03**	**23.53**	**24.28**	**27.31**	**10.7**	**24.28**	**14.59**
Capacity	**24 hours**				**15 hours**	**24 hours**	

6.2.2) Prioritisation of client rescheduling

From the evaluation of table 10; client 2, 4 and 5 have to be given priority when additional trains are scheduled as these are the clients to whom the volume delivered would be less than the volume required (budgeted). Where unutilized time is identified in the schedule, these clients are given priority when additional trains are scheduled.

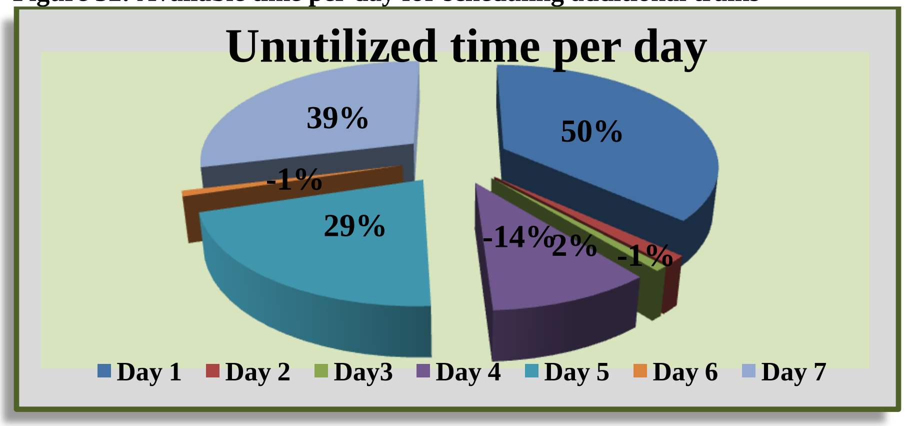
6.2.3) Scheduling Additional trains

The average total TAT time per day is calculated in the Utilization analysis (Table 10); which is then used to determine the average available TAT time per day. As seen in the figure below (Figure 30); Day 1, 5 and 7 are the days with available time for additional scheduling of trains with unutilized TAT times of 11.97 hours, 4.98 hours and 9.4 hours respectively.

From this evaluation of unutilized time per day; the following changes are made to the schedule to eliminate the constraints as well as to schedule additional trains to increase throughput where a balance of the actual production and budgeted production is required:

- Client 1 (Average TAT time 4.36 hrs) on day 4 is rescheduled to day 5 to remove weight off the over-utilization area (Day 4).
- Client 5(Average TAT time 6.14 hrs) and Client 2 (Average TAT time 4.49 hrs) are scheduled to the unutilized TAT time of 11.97 Hours on Day 1.
- Client 2(Average TAT time 4.49 hrs) and Client 4 (Average TAT time 4.12 hrs) are scheduled to the unutilized TAT time of 9.4 Hours on Day 7

Figure 32: Available time per day for scheduling additional trains



6.2.4) Improvement Evaluation

6.2.4.1) Monthly performance overview

The following monthly performance overview reflects results obtained from the proposed improvement scenario. Once again, the cumulative product delivery is represented for each client in order to assess whether the actual production for the month is at least equal to the budgeted volume of product for that specific client. The following diagrams represent the cumulative monthly performance in terms of throughput for each client:

Figure 33: Client1 Monthly performance

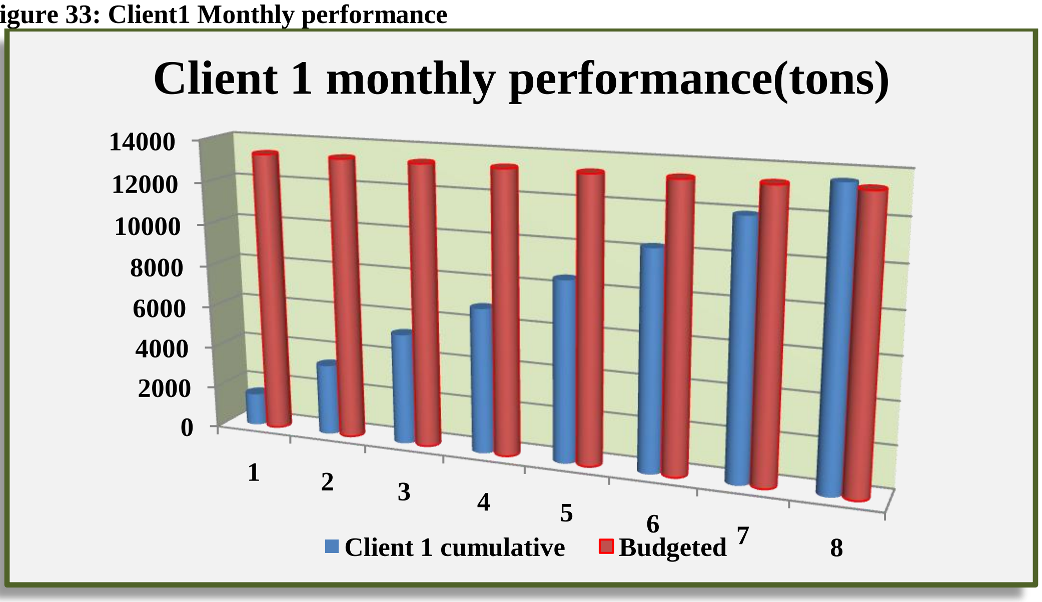


Figure 34: Client2 Monthly performance

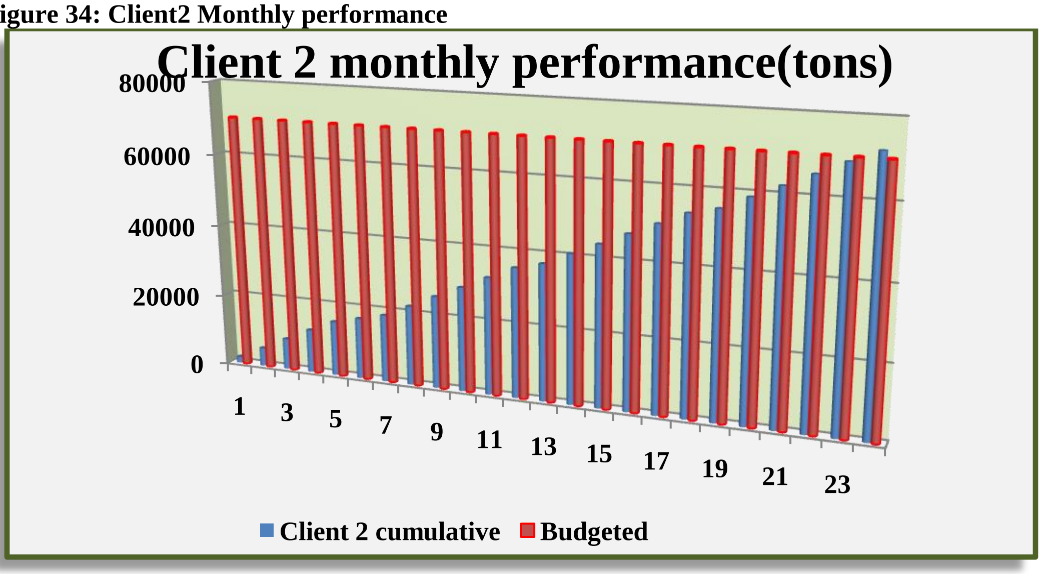


Figure 35: Client3 Monthly performance

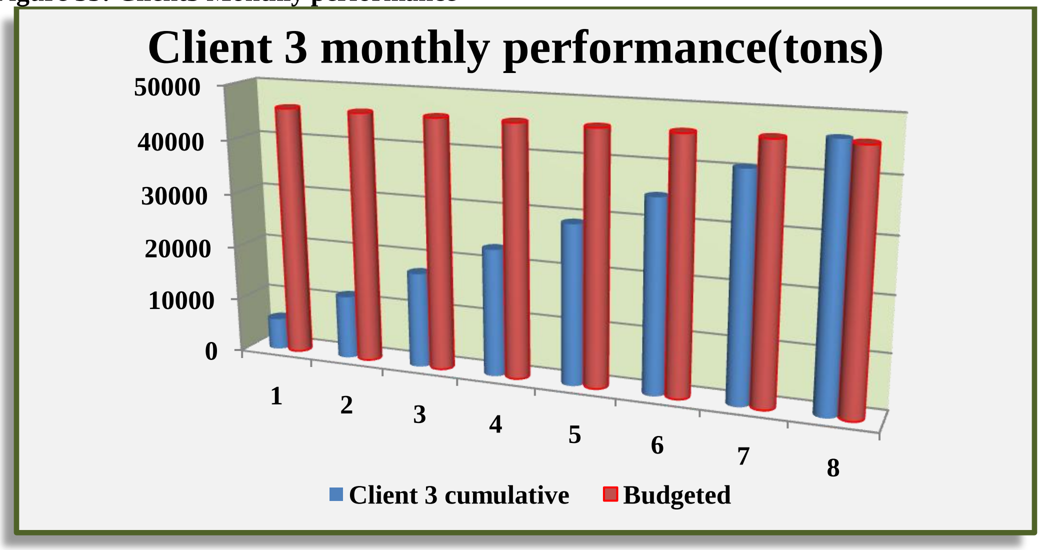


Figure 36: Client4 Monthly performance

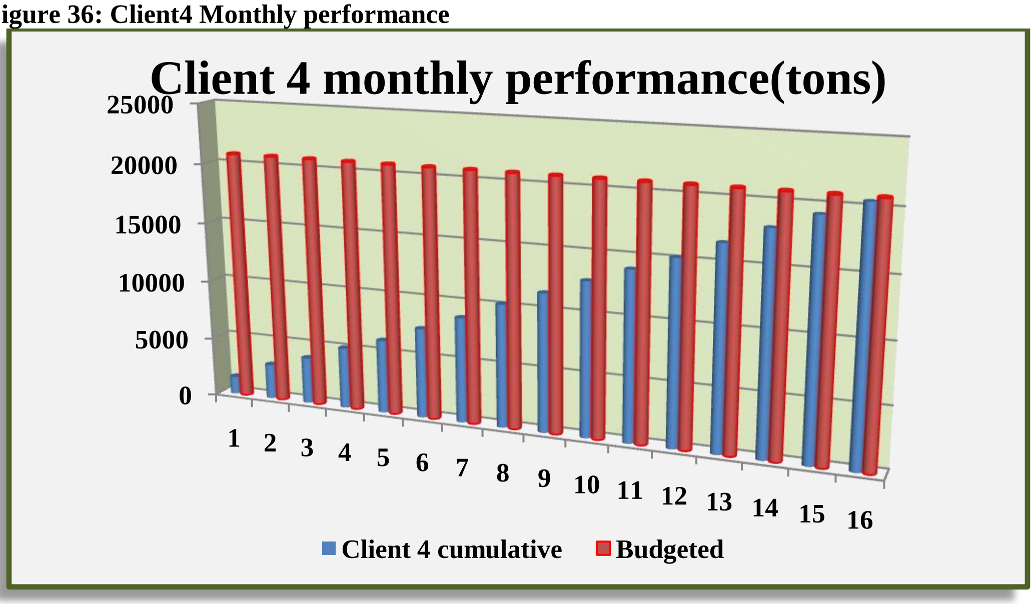


Figure 37: Client5 Monthly performance

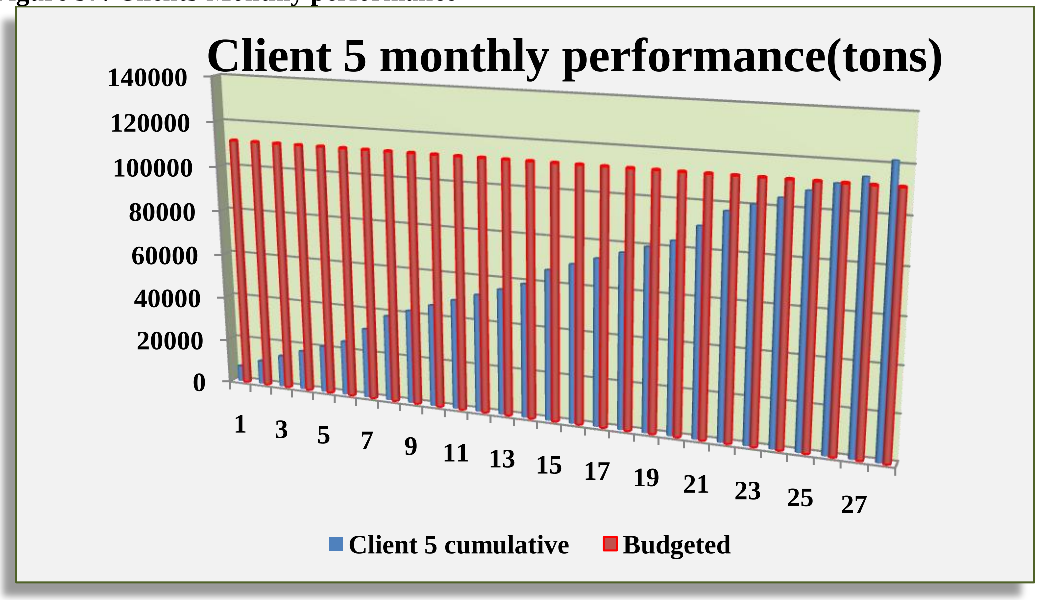


Figure 38: Client6 Monthly performance

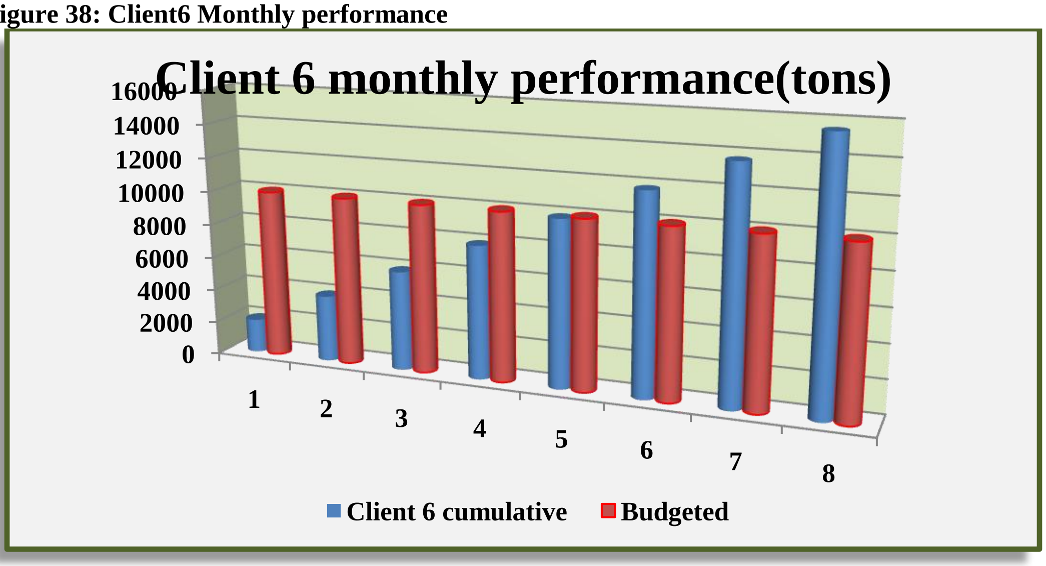


Table 13: Comparison of actual product versus budgeted volume

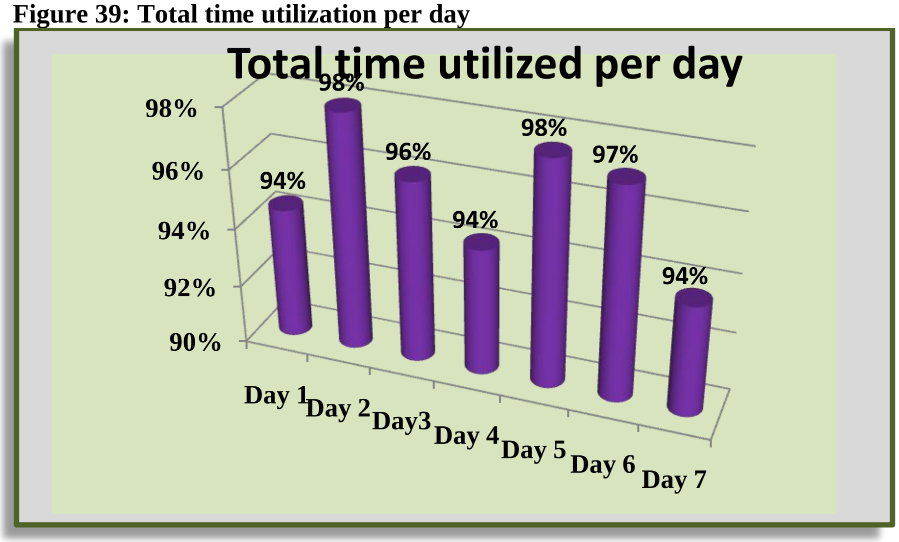
Monthly total	Client1	Client2	Client3	Client4	Client5	Client6
Actual(model)	13586.43	72199.54	46474.98	20506.62	121673.3	15551.71
Budgeted	13333	70250	45833	20833	111666	10000

From the monthly production results obtained above, it is evident that the proposed schedule will deliver satisfactory levels of production as required by the production budget. As seen from the table above, all budgeted production from client 1 to 6 is exceeded except for client 4.

Consignment to client 4 is not completely satisfactory but is acceptable as the stochastic nature of the process (Arena model) can deliver a range of product volumes as specified by the respective distributions and also because the deviation of actual production from the budgeted production is minimal.

The proposed improvement scenario also results in the effective utilization of the available time per day. The following figure represents the percentage of time utilized per day after the rescheduling of additional trains and removal of constraints:

Figure 39: Total time utilization per day



6.2.4.2) Utilization Analysis

Table 14: Utilization analysis

Replications	*Day 1*	*Day 2*	*Day3*	*Day 4*	*Day 5*	*Day 6*	*Day 7*
	TAT time (hours)						
Rep 1	22.38	23.31	23.98	24.09	14.38	22.06	22.04
Rep 2	22.23	22.58	23.11	21.7	14.92	23.34	22.9
Rep 3	22.16	22.31	23.75	20.43	15.05	25.88	23.17
Rep 4	22.75	24.81	22.43	26.44	14.74	22.56	23.12
Rep 5	24.53	24.45	21.98	22.22	13.23	23.67	21.8
Rep 6	23.5	25.32	22.29	23.39	14.94	21.03	22.83
Rep 7	21.42	24.43	23.63	23.07	15.43	23.15	21.94
Rep 8	22.69	22.55	23.82	23.81	14.16	23.14	22.25
Rep 9	22.59	23.33	23.98	21.11	14.91	25.9	22.89
Rep 10	22.38	22.08	21.78	20.07	14.56	22.46	22.04
Average Demand	22.663	23.517	23.075	22.633	14.64	23.319	22.498
Capacity	**24 hours**				**15hours**	**24 hours**	

From the Utilization analysis above, it can be concluded that the major system overloading areas have been removed by rescheduling of trains where trains are rescheduled from overloaded days to less utilized days. Rescheduling also entails the addition of trains where idle time is available to be used.

Although the inputs and results delivered by Arena are stochastic, the average values from ten replications give an accurate enough estimation of how well the system will perform once the proposed schedule is implemented.

6.2.4.3) Proposed Train arrival schedule

The following table represents the train loading schedule proposed as a result of the formulation of the improvement scenario discussed above. The schedule is similar to the previous schedule discussed earlier in the report with changes made where constraints in the schedule were eliminated and additional trains scheduled to improve system performance and therefore throughput.

Table 15: Proposed train loading schedule

Day	Train Number	Nr of Trains/day	Product	Client
Sunday	101	4	Product A	Customer 5
	102		Product A	Customer 5
	103		Product A	Customer 5
	104		Product D	Customer 2
Monday	201	4	Product D	Customer 2
	202		Product A	Customer 5
	203		Product D	Customer 2
	204		Product C	Customer 3
Tuesday	301	5	Product D	Customer 2
	302		Product B	Customer 4
	303		Product A	Customer 5
	304		Product D	Customer 6
	305		Product D	Customer 2
	306			
Wednesday	401	4	Product D	Customer 2
	402		Product A	Customer 5
	403		Product D	Customer 2
	404		Product C	Customer 3
Thursday	501	3	Product A	Customer 5
	502		Product B	Customer 4
	503		Product B	Customer 1
	504			
Friday	601	5	Product D	Customer 2
	602		Product A	Customer 5
	603		Product D	Customer 6
	604		Product D	Customer 2
	605		Product B	Customer 1
Saturday	701	5	Product D	Customer 2
	702		Product A	Customer 5
	703		Product B	Customer 4
	704		Product D	Customer 2
	705		Product B	Customer 4

6.3) Improvement Scenario 2

The major system changes made are:

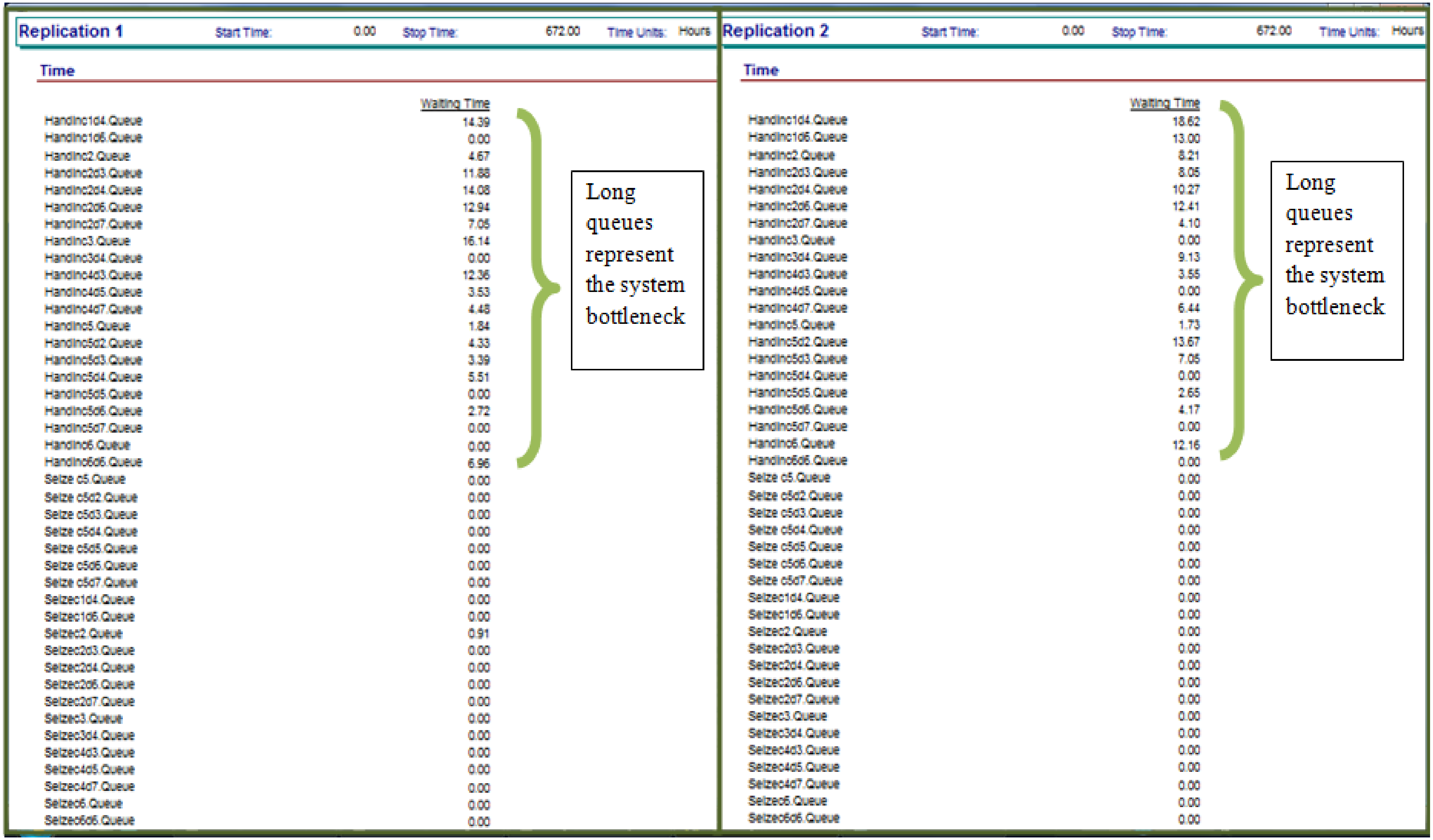
- Maintaining high conveyor belt speeds
- Ensure a large weigh bin discharge gate to provide sufficient flow rate to load the train before it leaves the station
- Ensure closer stockpiles to reduce the reclaiming times and maintain high reclaiming rates by ensuring the correct quality of product delivered to the stockpiles
- Ensure fast and secure handovers

The proposed changes will ensure higher flow rates and thus increase the amount of tons loaded as well as reduce the loading times. From the Data Distributions presented earlier in the report, flow rates/ loading tempos are assumed to be increase by at least a third to maintain medium to high flow rates from the triangular distributions; e.g. if the loading tempo distribution for a client1 was TRIA (10, 16.8, 37) it will be assumed that a high tempo is maintained at UNIF (16.8, 37). The complementary changes will therefore be the same for the Loading duration and the amount of tons loaded.

6.3.1) Theory of constraints Analysis

The theory of constraints is implemented to identify system constraints and eliminate those constraints in order to reduce operational expenses and improve throughput. According to Aquilano et al 2009, one of Goldratt's rules for production scheduling is that "An hour lost at a bottleneck is an hour lost for the entire system". Elimination of bottlenecks is an effort to save operating expenses and increase throughput. After the bottleneck is identified in the figure below, a fishbone diagram is used to identify causes of the system bottleneck effect. From the identification of the problem causes, changes are proposed to the system in order to eliminate the system constraint. (Refer to the figures below for the analysis)

Figure 40: Queue analysis for TOC



Replication 1 — Start Time: 0.00 — Stop Time: 672.00 — Time Units: Hours

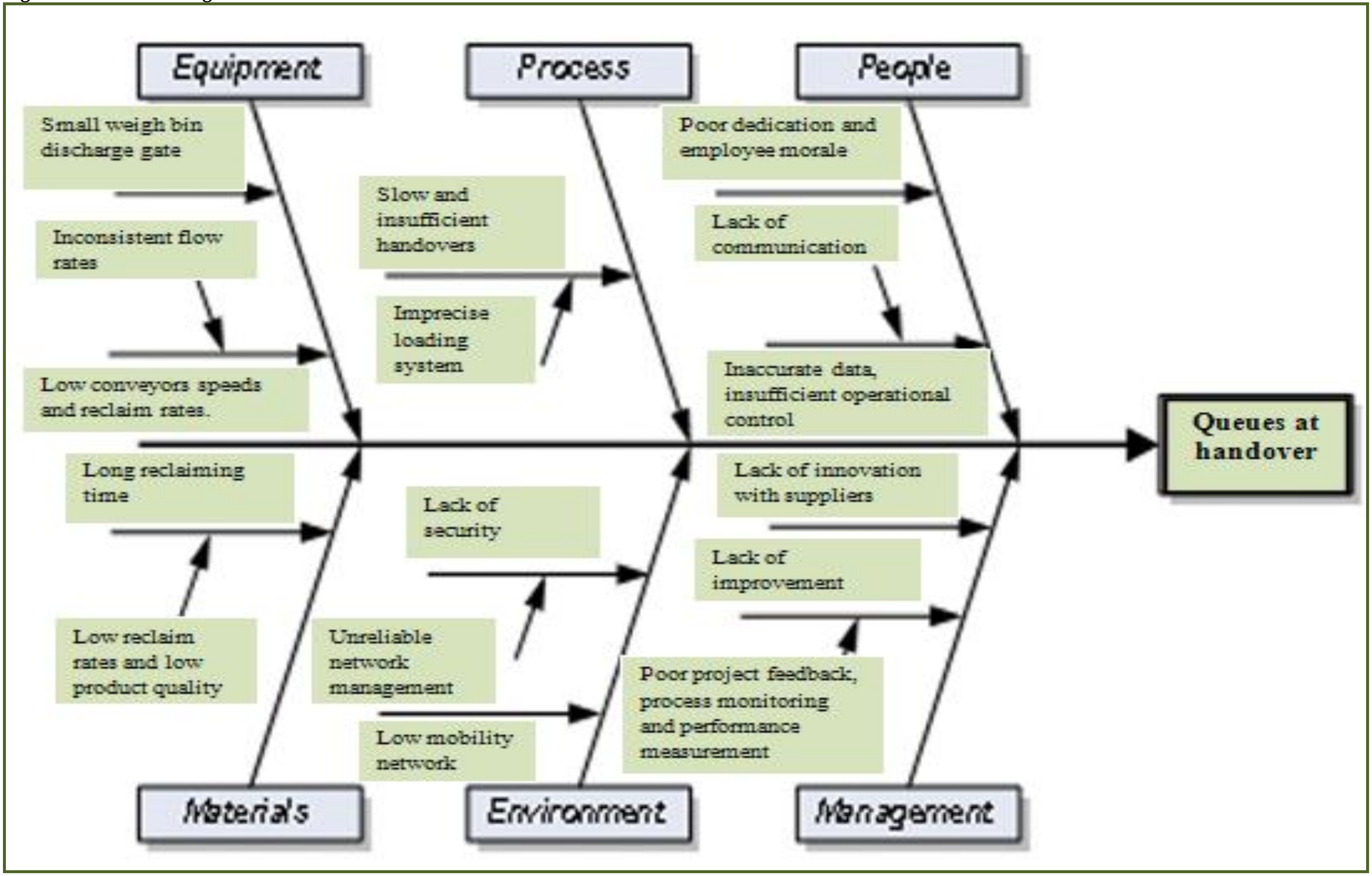
Replication 2 — Start Time: 0.00 — Stop Time: 672.00 — Time Units: Hours

Time

Queue	Replication 1 Waiting Time	Replication 2 Waiting Time
Handinc1d4.Queue	14.39	18.62
Handinc1d6.Queue	0.00	13.00
Handinc2.Queue	4.67	8.21
Handinc2d3.Queue	11.88	8.05
Handinc2d4.Queue	14.08	10.27
Handinc2d6.Queue	12.94	12.41
Handinc2d7.Queue	7.05	4.10
Handinc3.Queue	16.14	0.00
Handinc3d4.Queue	0.00	9.13
Handinc4d3.Queue	12.36	3.55
Handinc4d5.Queue	3.53	0.00
Handinc4d7.Queue	4.48	6.44
Handinc5.Queue	1.84	1.73
Handinc5d2.Queue	4.33	13.67
Handinc5d3.Queue	3.39	7.05
Handinc5d4.Queue	5.51	0.00
Handinc5d5.Queue	0.00	2.65
Handinc5d6.Queue	2.72	4.17
Handinc5d7.Queue	0.00	0.00
Handinc6.Queue	0.00	12.16
Handinc6d6.Queue	6.96	0.00
Seize c5.Queue	0.00	0.00
Seize c5d2.Queue	0.00	0.00
Seize c5d3.Queue	0.00	0.00
Seize c5d4.Queue	0.00	0.00
Seize c5d5.Queue	0.00	0.00
Seize c5d6.Queue	0.00	0.00
Seize c5d7.Queue	0.00	0.00
Seizec1d4.Queue	0.00	0.00
Seizec1d6.Queue	0.00	0.00
Seizec2.Queue	0.91	0.00
Seizec2d3.Queue	0.00	0.00
Seizec2d4.Queue	0.00	0.00
Seizec2d6.Queue	0.00	0.00
Seizec2d7.Queue	0.00	0.00
Seizec3.Queue	0.00	0.00
Seizec3d4.Queue	0.00	0.00
Seizec4d3.Queue	0.00	0.00
Seizec4d5.Queue	0.00	0.00
Seizec4d7.Queue	0.00	0.00
Seizec6.Queue	0.00	0.00
Seizec6d6.Queue	0.00	0.00

Long queues represent the system bottleneck

Figure 41: Fishbone diagram



6.3.2) Improvement Evaluation

6.3.2.1) Throughput improvement analysis

A throughput improvement analysis is done on the proposed scenario to evaluate whether the removal and elevation of the system constraints indeed has a positive effect on throughput. The following graphs represent the difference in monthly throughput for the current and improved scenarios as well as an analysis of whether the scenarios reach the monthly production target:

Figure 42: Client 1 Throughput improvement analysis

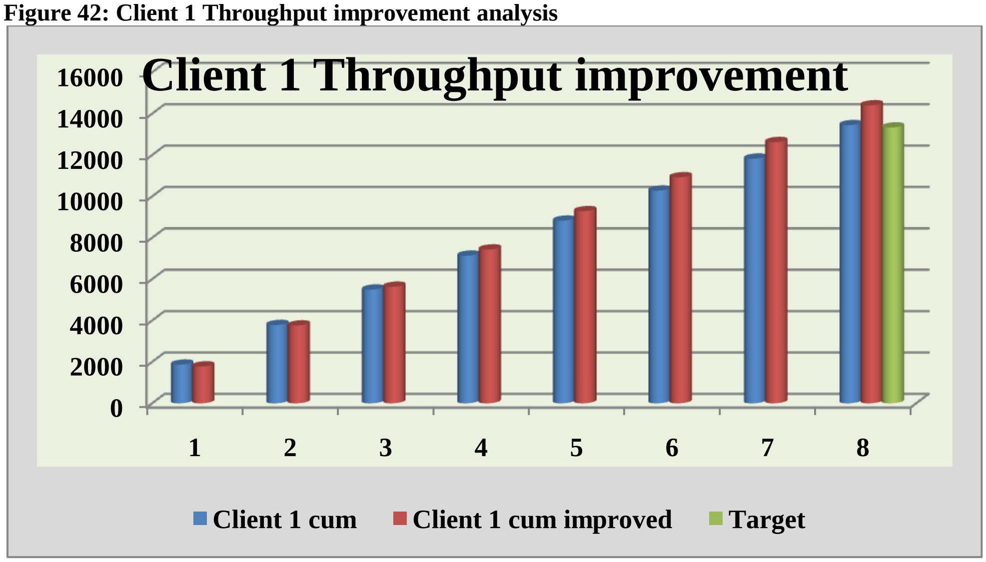


Figure 43: Client 2 Throughput improvement analysis

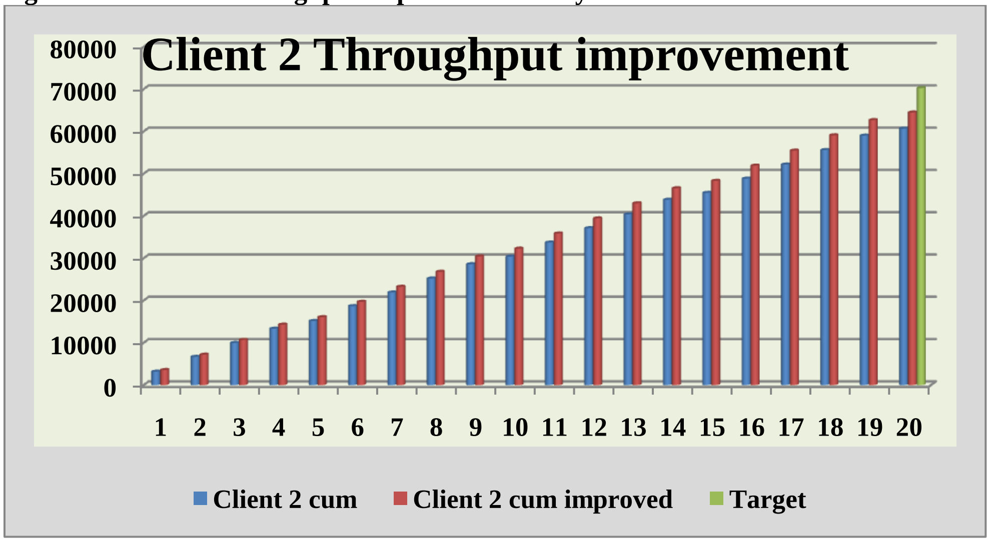


Figure 44: Client 3 Throughput improvement analysis

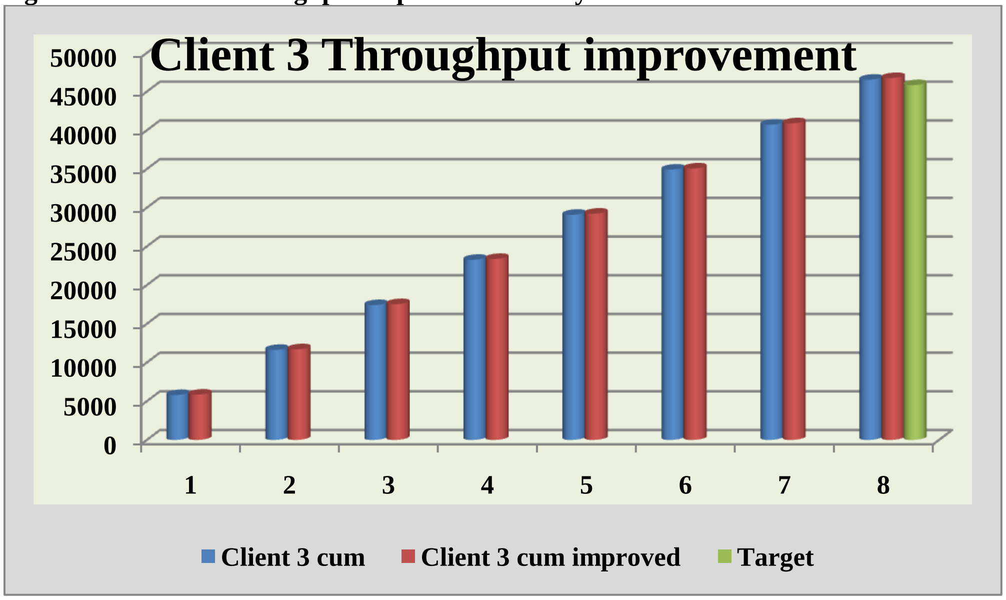


Figure 45: Client 4 Throughput improvement analysis

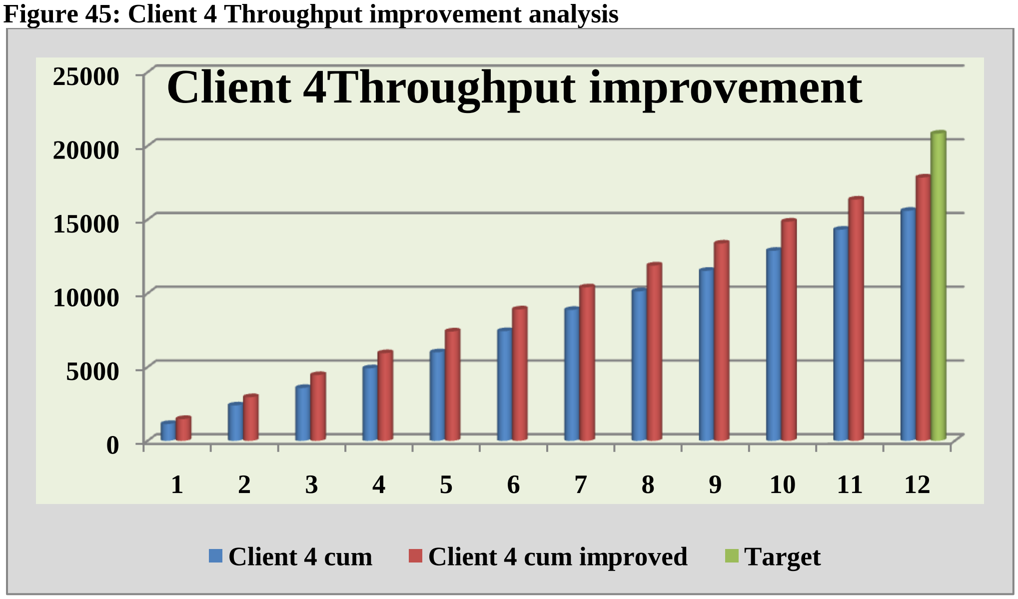


Figure 46: Client 5 Throughput improvement analysis

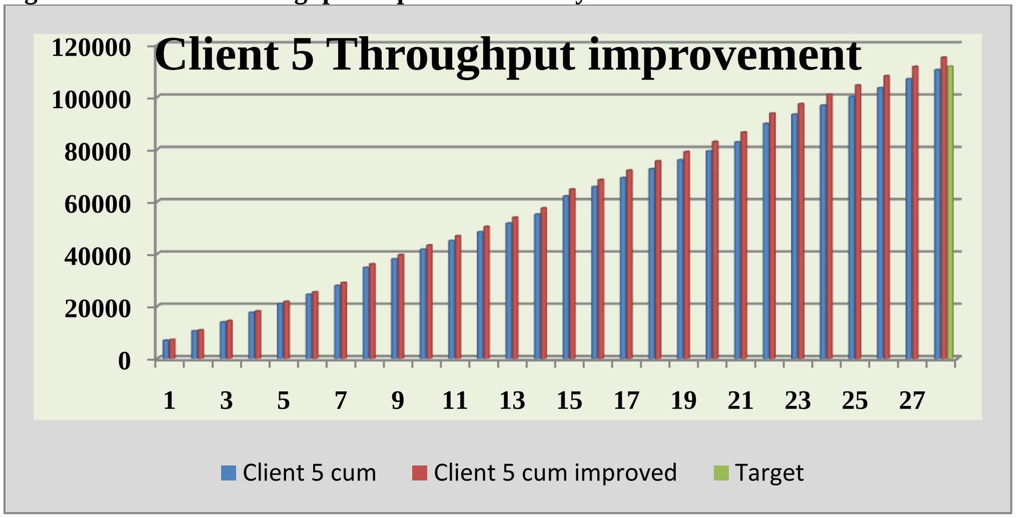


Figure 47: Client 6 Throughput improvement analysis

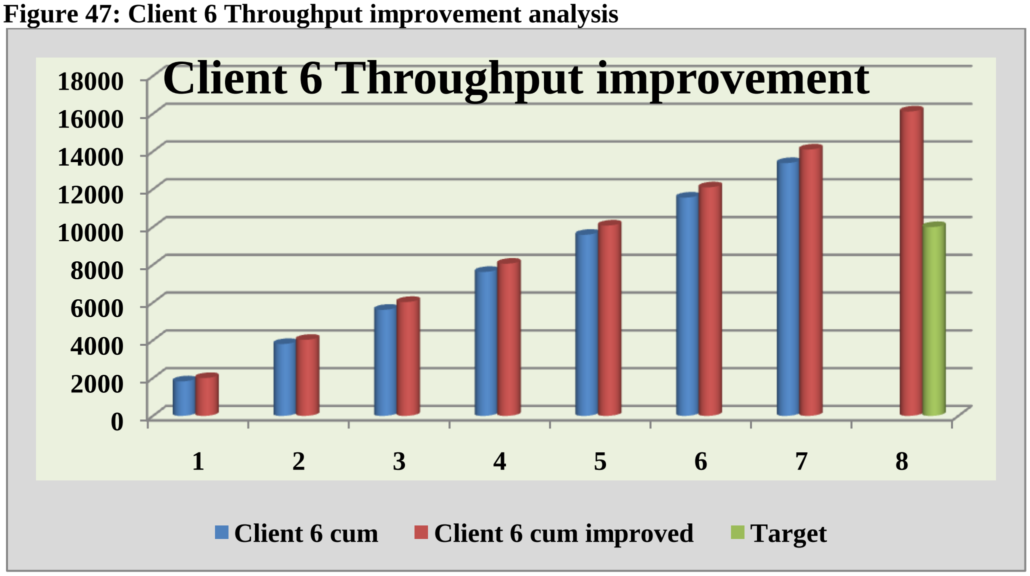


Table 16: Throughput improvement analysis

Monthly Production	Client1	Client2	Client3	Client4	Client5	Client6
Current scenario	13447	60657	46538	15596	110378	15310
Improvement scenario	14405.97	64475.3	46752.9	17856.19	115112.8	16121.69
Budgeted	13333	70250	45833	20833	111666	10000

From the throughput improvement analysis, a conclusion can be made that the reduction of the waiting time (queue length) at the system bottleneck results in a significant increase in throughput for clients 1 to 6, although attention should be given to the consignment and additional scheduling of clients 2 and 6 as the product delivery for these clients does not meet the monthly target.

6.3.2.2) System time reduction analysis

The following table shows the significant decrease in TAT times from the current scenario due to the elimination of the system constraints. The increase in product flow rate influences the loading and handover times (decreased) and thus decreases the overall TAT time for client loading. Refer to Appendix G for a representation of the reduction in queue waiting time at the bottleneck as a result of the proposed changes.

Table 17: TAT time reduction analysis

Replications	*Day 1*	*Day 2*	*Day3*	*Day 4*	*Day 5*	*Day 6*	*Day 7*
	TAT time (hours)						
Rep 1	**9.27**	**19.31**	**18.17**	**22.21**	**8.55**	**18.38**	**12.19**
Rep 2	**9.43**	**19.71**	**19.25**	**22.68**	**7.91**	**19.85**	**11.44**
Rep 3	**9.85**	**19.09**	**19.83**	**23.04**	**8.21**	**18.98**	**12.03**
Rep 4	**9.85**	**18.39**	**19.64**	**23.17**	**8.3**	**19.37**	**11.67**
Rep 5	**8.79**	**19.8**	**20.32**	**21.57**	**8.48**	**19.12**	**12.42**
Average Utilization	**9.438**	**19.26**	**19.442**	**22.534**	**8.29**	**19.14**	**11.95**
Capacity	**24 hours**				**15hours**	**24 hours**	

Chapter 7

Conclusion and Recommendations

In conclusion, the simulation model was a relevant technique to determine the capability of the load out station and all associated operational resources. The analysis of the current operation's simulation model has aided in the exploration of improvement opportunities as it was discovered that the throughput obtained from the current system did not meet the budgeted production level.

The current system was certainly capable of performing better despite the limited resources; all available time and operational resources were used to improve the system's performance by increasing the utilization level of the resources, increasing throughput, eliminating constraints and also reducing the chances of failure to meet proposed changes.

Changes made to the current scenario entail; balancing the daily time utilization by rescheduling the client with the least TAT time from day4 to day 5, and bringing under-consigned customers to reconciliation by scheduling additional trains to those customers to days (day1 and day7) where there was unutilized time available.

The high utilization of daily time available in the proposed operational scenario could be a risk to the system in cases of major system disruptions or unplanned downtime; but the available 9hours on day5 every first week that planned maintenance is not conducted (planned maintenance is scheduled for every second Thursday) could serve as buffer time for unexpected time losses or system failure.

The second improvement scenario uses TOC which focuses on the reduction of queue waiting time at the system bottleneck to reduce operational expenses, reduce inventory and increase throughput.

Improvement scenario 1 is a more costly, time consuming proposition which requires higher authorization and multi-channel consultation where implementation is long-term and can only occur for example once a year.

Improvement scenario 2 is a continuous improvement effort that is less complicated to implement than Alternative 1. It is recommended that this alternative be implemented, although additional scheduling could further address the problem of client consignment not reaching the monthly target (client 2 and client 4). It is further recommended that upon implementation of Scenario 1, the analysis and process followed in scenario 2 is also implemented as this will ensure the elimination of unforeseen system constraints before attempting to reschedule or add more trains to the arrival schedule as this will ensure thorough and efficient system exploration, higher throughput improvement and efficient operational performance.

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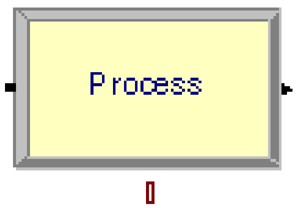
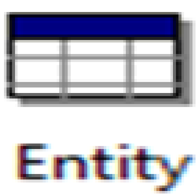
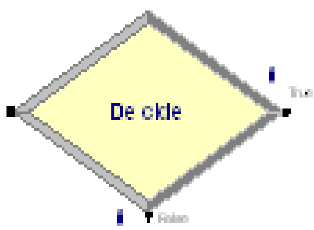
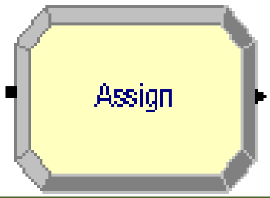
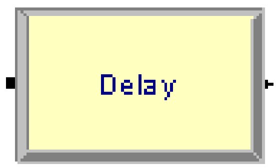
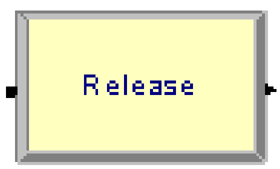
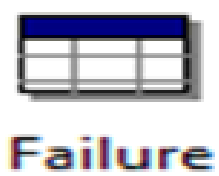
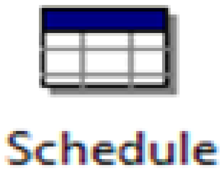
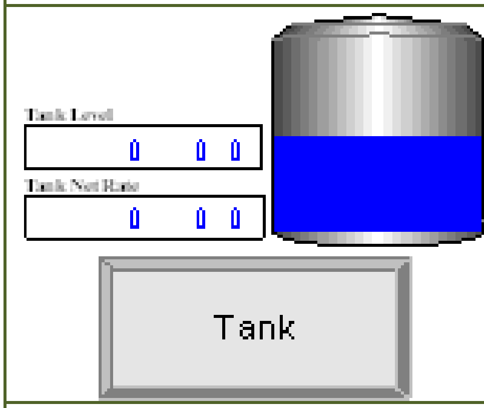
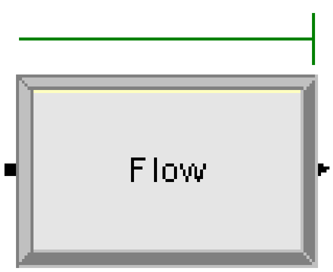
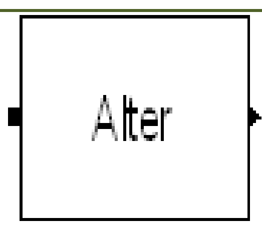
Appendix A

Table 18: Arena model components and descriptions

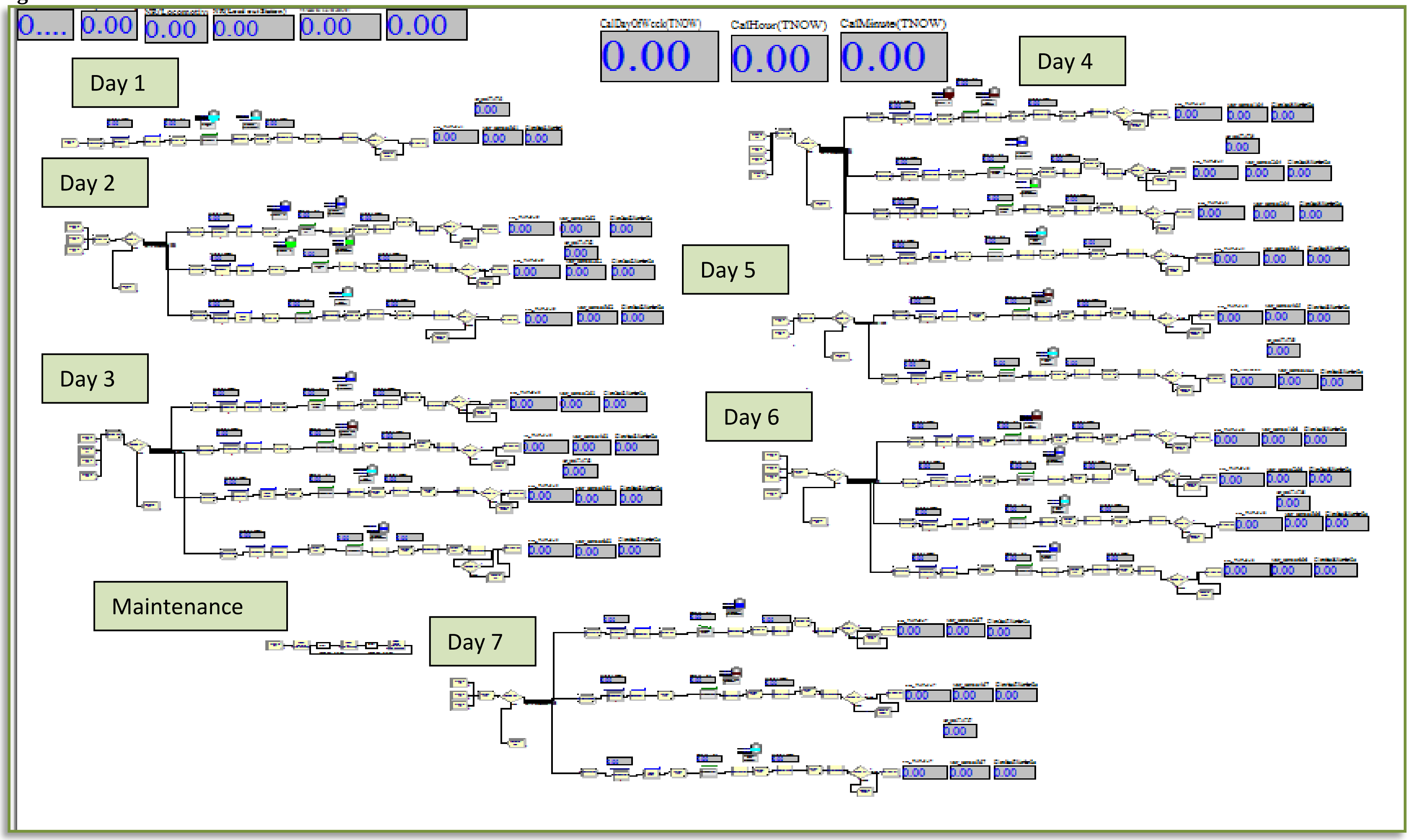
	This is the starting point for all entities that should enter the system to be processed. This module accommodates the creation of entities based on a schedule or time between arrivals which have to be defined by the user.
	The process module is intended to be the main processing area in the model where the seizing and releasing of resources can take place. Resources as well as their failures are listed. The time elapsed for the processing should be recorded in this module.
	This element allows the user to list and define the resources with regards to their capacities, costs and failures.
	The entity element registers all entities created within the Create modules. Entity pictures as well as entity costs are all also recorded if necessary.
	The decide module allows decision making processes within the model. The decisions to be made are based on either certain conditions or probabilities based on entities, attribute values, variables and expressions.
	Collections of all types of statistics including observational statistics, time statistics, interval statistics and entity statistics can be made using this module. Count statistics can also be evaluated through this module.

	This module is used to assign new values to variables, entity attributes, entity types, entity pictures, or other system variables. More than one assignment can be made to a single assign module.
	The allocation of resources to the system entities is done through this module. When resources are allocated to entities, the entities have to wait in a queue for the specified allocation sequence.
	The Delay module is used to represent system delays or processes where entities are delayed for the amount of time specified within the delay module. Associated times and costs could be calculated and allocated using this module.
	This module releases resources or units thereof that have previously been seized, therefore causing the entity to give up the control it had of the resources previously seized. The name and quantity of the resources to be released should be specified.
	The Failure element allows the user to register resource failure probabilities which include the operational time between failures and the probabilistic times it takes before the resources can be repaired. All failure counts or times are linked directly to a resource or a unit thereof.
	The recording of all queues as well as the serving sequence of that particular queue is done by this element. The default registration of queues is done by Arena for every process where the 'Seize' action is involved.
	The Dispose module represents the exit point for all entities within the system.

	Schedules recorded at the arrival of entities as the type of control the processes arrivals are defined by making use of this element. A schedule can be defined as an arrival or capacity schedule and further defined in terms of capacity of arrivals or incidences as well the duration of time in which they occur.
	Global variables and their initial values can be defined and stored using this module. Real-valued quantities stored within the variables can then be reassigned or animated later in the simulation run.
	This module represents a holding area for the storage of material where defined regulators control the continuous/semi-continuous flow of material that goes in and out of the specific holding area.
	The flow module works together with the tank module to represent the semi-continuous flow operations such as the transfer of materials and the adding or removing of material from the tank.
	The Alter block is used to affect the capacity of a busy resource by immediately reducing its capacity and thus making it unavailable and altering the resource capacity again to make it available.

Appendix B

Figure 48: Overview of Arena model



Appendix C

Figure 49: Distribution fit data selection

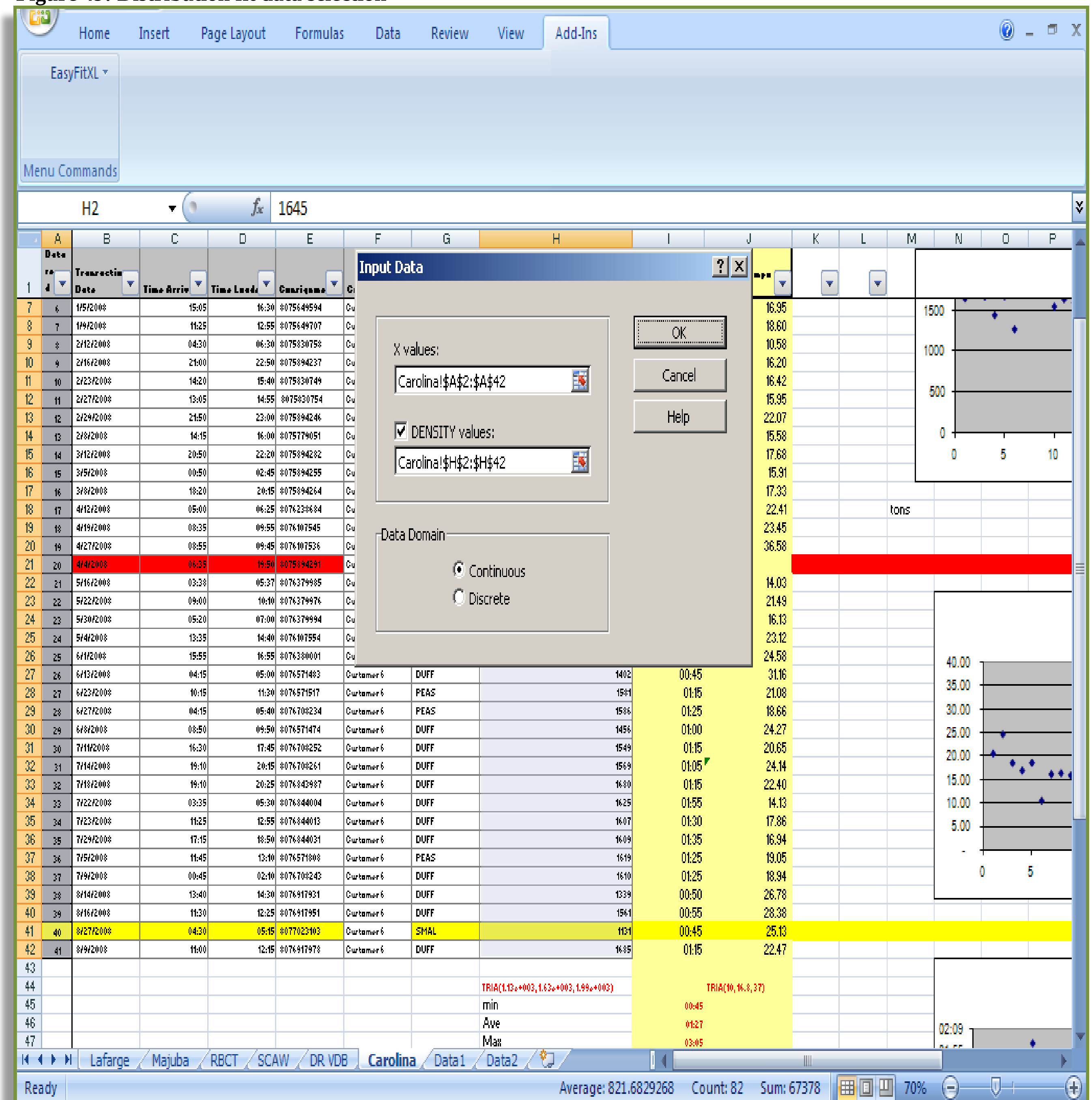


Figure 50: Distribution fit graph representation

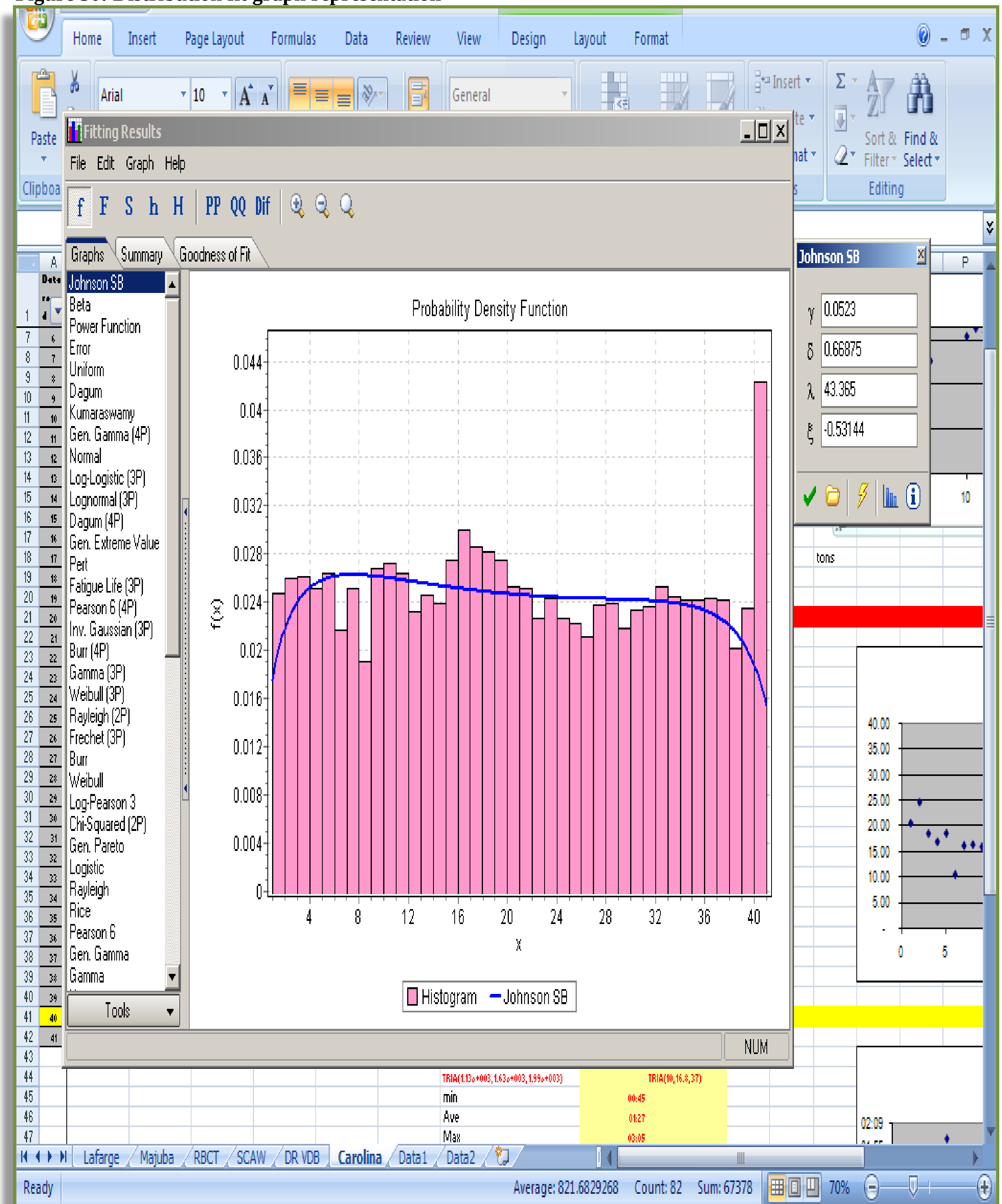


Figure 51: Goodness of fit execution

File Edit Graph Help

f F S h H PP QQ Dif

Graphs | Summary | Goodness of Fit

Goodness of Fit - Summary

#	Distribution	Kolmogorov Smirnov		Anderson Darling	
		Statistic	Rank	Statistic	Rank
1	Beta	0.02472	2	3.8909	45
2	Burr	0.08364	23	0.77537	19
3	Burr (4P)	0.07459	18	0.58995	13
4	Cauchy	0.13541	42	1.1254	25
5	Chi-Squared	0.22065	53	15.566	55
6	Chi-Squared (2P)	0.08807	26	0.71106	18
7	Dagum	0.04859	6	29.569	57
8	Dagum (4P)	0.07289	12	0.6675	16
9	Erlang	0.11736	38	1.7964	36
10	Erlang (3P)	0.10648	35	1.0109	23
11	Error	0.02728	4	0.07497	2
12	Error Function	0.58479	58	61.669	58
13	Exponential	0.17186	47	2.8202	40
14	Exponential (2P)	0.16516	46	3.1169	41
15	Fatigue Life	0.19816	50	3.1351	42
16	Fatigue Life (3P)	0.07315	15	0.55094	7
17	Frechet	0.21069	52	3.6842	44
18	Frechet (3P)	0.08179	22	0.70624	17
19	Gamma	0.10332	33	1.6686	33
20	Gamma (3P)	0.07468	19	0.57374	10
21	Gen. Extreme Value	0.07289	13	0.58244	12
22	Gen. Gamma	0.10221	32	1.177	27

NUM

Appendix D

Table 19: Detailed Overview of monthly performance

Week 1 (tons)						
	Client1	*Client2*	*Client3*	*Client4*	*Client5*	*Client6*
Day 1					6915.66	
Day 2		3182.8	5804.12		3576.45	
Day 3		3497.03		1139.13	3437.89	1827.1
Day 4	1867.9	3303.03	5824.57		3649.76	
Day 5				1258.79	3336.73	
Day 6	1916.49	3367.42			3530.06	1981.25
Day 7		1803.64		1186.8	3410.93	
Total	**3784.39**	**15153.92**	**11628.69**	**3584.72**	**27857.48**	**3808.35**
Week 2 (tons)						
	Client1	*Client2*	*Client3*	*Client4*	*Client5*	*Client6*
Day 1					6879.97	
Day 2		3520.07	5790.89		3286.94	
Day 3		3244.26		1328.94	3665.33	1810
Day 4	1713.1	3314.42	5847.68		3315.14	
Day 5				1088.41	3355.73	
Day 6	1639.05	3361.69			3315.91	2006.66
Day 7		1792.91		1435.55	3446.21	
Total	**3352.15**	**15233.35**	**11638.57**	**3852.9**	**27265.23**	**3816.66**
Week 3 (tons)						
	Client1	*Client2*	*Client3*	*Client4*	*Client5*	*Client6*
Day 1					6957.92	
Day 2		3334.52	5815.03		3528.92	
Day 3		3390.47		1438.82	3467.44	1965.72
Day 4	1692.39	3269.24	5842.86		3407.55	
Day 5				1256.98	3386.64	
Day 6	1452.27	3459.6			3376.84	1970.17
Day 7		1618.32		1393.85	3455.95	
Total	**3144.66**	**15072.15**	**11657.89**	**4089.65**	**27581.26**	**3935.89**
Week 4 (tons)						
	Client1	*Client2*	*Client3*	*Client4*	*Client5*	*Client6*
Day 1					7086.09	
Day 2		3380.81	5795.57		3508.2	
Day 3		3324.78		1358.48	3507.11	1828.19
Day 4	1546.31	3429.93	5817.62		3223.03	
Day 5				1430.9	3408.19	
Day 6	1619.43	3423.97			3407.78	1921.15
Day 7		1638.64		1279.85	3533.75	

Total	3165.74	15198.13	11613.19	4069.23	27674.15	3749.34

Appendix E

Figure 52: Input analyzer data selection

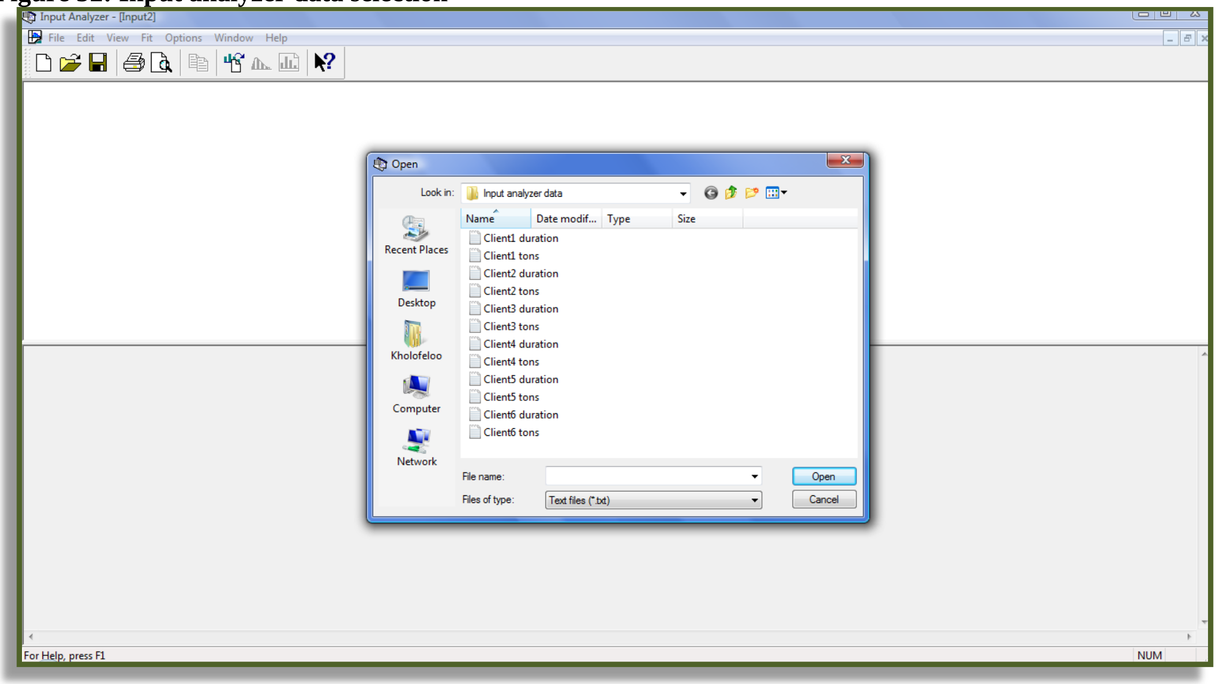


Figure 53: Input analyzer distribution fitting

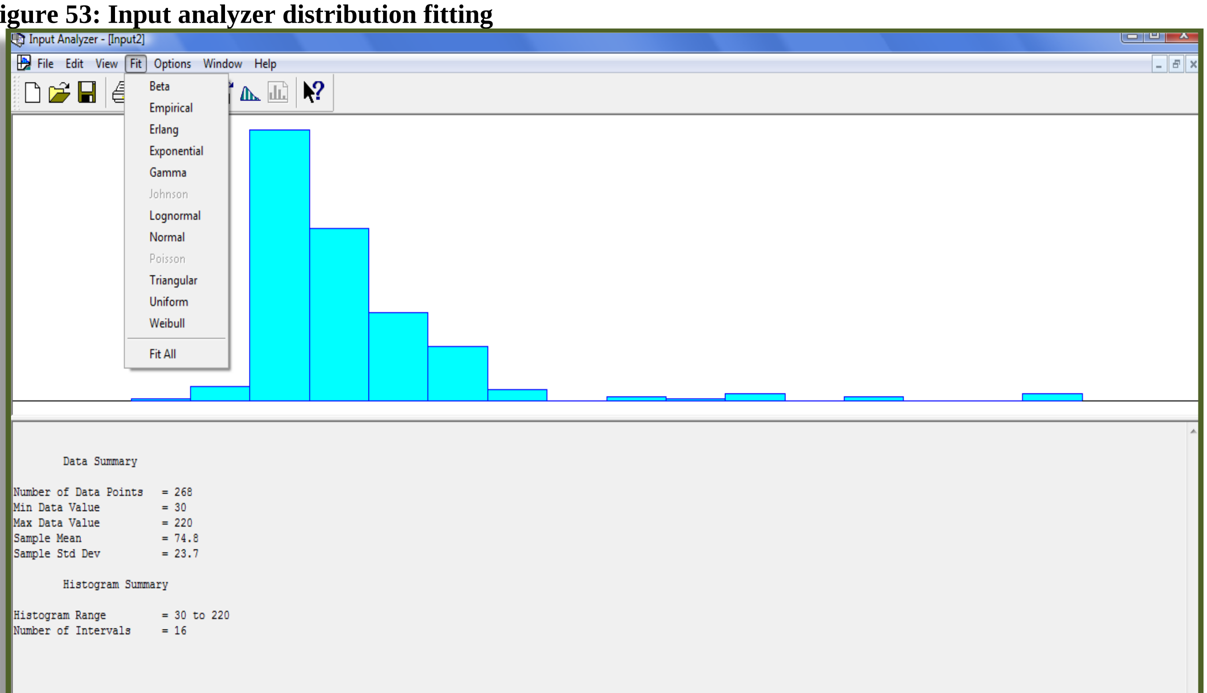
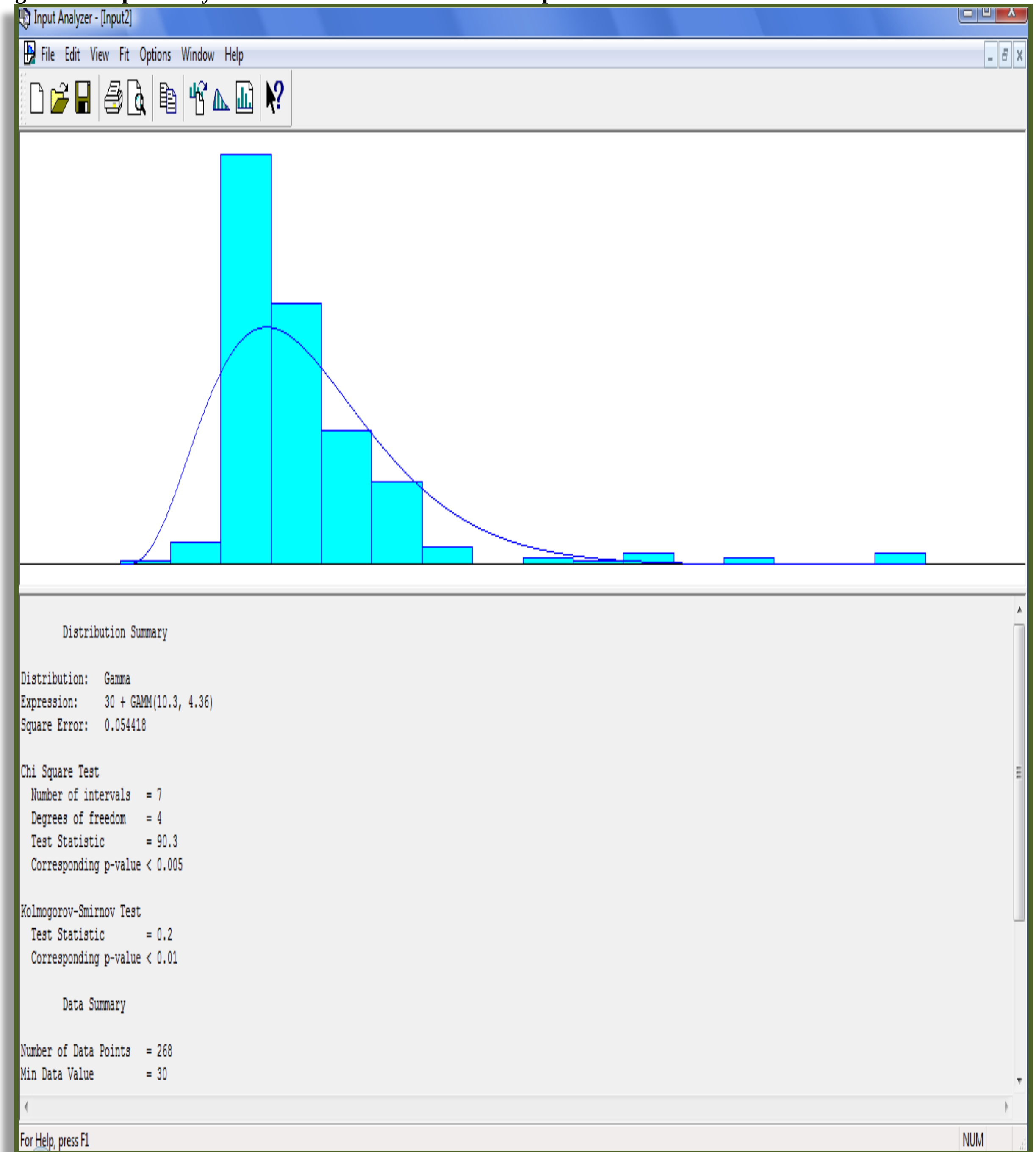


Figure 54: Input analyzer best distribution and Arena expression



Appendix F

Table 20: Calculation of Average TAT times

Average TAT times (hours)						
	Week1	*Week2*	*Week3*	*Week4*	*Week5*	Average
Day 1						
c5d1(2)	11.63	11.9	13.06	12.77	10.43	5.979
Day2						
c2d2(2)	10.01	8.06	7.38	8.36	9.39	4.32
c3d2	8.71	9.43	10.05	8.56	9.13	9.176
c5d2	6.27	6.82	4.98	5.21	5.64	5.784
Day3						
c2d3(2)	9.48	8.85	9.45	8.13	10.56	4.647
c4d3	3.8	3.83	4.98	4.44	3.55	4.12
c5d3	5.46	6.54	6.93	7.02	7.88	6.766
c6d3	3.55	4.55	4.36	4.52	4.57	4.31
Day4						
c1d4	3.52	4.14	4.54	4.95	4.06	4.242
c2d4(2)	9.18	8.16	7.65	9.65	8.68	4.332
c3d4	8	8.16	7.61	8.86	7.28	7.982
c5d4	5.41	6.71	6.08	5.5	5.05	5.75
Day5						
c4d5	4.69	3.47	3.64	3.42	4.67	3.978
c5d5	7.92	6.1	6.66	6.88	5.97	6.706
Day6						
c1d6	4.24	4.14	4.39	4.88	4.73	4.476
c2d6(2)	7.57	9.37	9.61	10.1	8.95	4.56
c5d6	5.43	6.16	6.15	5.16	7.09	5.998
c6d6	5.1	5.07	3.49	4.39	3.49	4.308
Day7						
c2d7	5.08	4.22	5.2	4.31	4.1	4.582
c4d7	4.55	4.48	4.88	3.21	4.17	4.258
c5d7	5.12	5.17	5.39	6.41	7.88	5.994
Average TAT times						
Client1	***Client2***	***Client3***	***Client4***	***Client5***	***Client6***	
4.359	**4.4882**	**8.579**	**4.118667**	**6.139571**	**4.309**	

Appendix G

Figure 55: Reduced queue waiting time

Replication 1 Start Time: 0.00 Stop Time: 672.00 Time Units: Hour

Time

	Waiting Time
HandInc1d4.Queue	13.20
HandInc1d6.Queue	0.00
HandInc2.Queue	3.93
HandInc2d3.Queue	10.88
HandInc2d4.Queue	13.12
HandInc2d6.Queue	11.70
HandInc2d7.Queue	3.61
HandInc3.Queue	11.13
HandInc3d4.Queue	0.00
HandInc4d3.Queue	11.12
HandInc4d5.Queue	2.88
HandInc4d7.Queue	8.54
HandInc5.Queue	1.72
HandInc5d2.Queue	3.57
HandInc5d3.Queue	3.27
HandInc5d4.Queue	5.37
HandInc5d5.Queue	0.00
HandInc5d6.Queue	2.64
HandInc5d7.Queue	1.10
HandInc6.Queue	0.00
HandInc6d6.Queue	6.68
Seize c5.Queue	0.00
Seize c5d2.Queue	0.00
Seize c5d3.Queue	0.00
Seize c5d4.Queue	0.00
Seize c5d5.Queue	0.00
Seize c5d6.Queue	0.00
Seize c5d7.Queue	0.00
Seizec1d4.Queue	0.00
Seizec1d6.Queue	0.00
Seizec2.Queue	0.00
Seizec2d3.Queue	0.00
Seizec2d4.Queue	0.00
Seizec2d6.Queue	0.00
Seizec2d7.Queue	0.00
Seizec3.Queue	0.00
Seizec3d4.Queue	0.00
Seizec4d3.Queue	0.00
Seizec4d5.Queue	0.00
Seizec4d7.Queue	0.00
Seizec6.Queue	0.00
Seizec6d6.Queue	0.00

Decreased bottleneck queue waiting times

Replication 2 Start Time: 0.00 Stop Time: 672.00 Time Units: H

Time

	Waiting Time
HandInc1d4.Queue	16.53
HandInc1d6.Queue	11.45
HandInc2.Queue	7.60
HandInc2d3.Queue	7.20
HandInc2d4.Queue	9.10
HandInc2d6.Queue	11.00
HandInc2d7.Queue	3.97
HandInc3.Queue	0.00
HandInc3d4.Queue	7.89
HandInc4d3.Queue	3.22
HandInc4d5.Queue	0.00
HandInc4d7.Queue	5.83
HandInc5.Queue	1.61
HandInc5d2.Queue	13.63
HandInc5d3.Queue	6.39
HandInc5d4.Queue	0.00
HandInc5d5.Queue	2.67
HandInc5d6.Queue	3.62
HandInc5d7.Queue	0.00
HandInc6.Queue	10.85
HandInc6d6.Queue	0.00
Seize c5.Queue	0.00
Seize c5d2.Queue	0.00
Seize c5d3.Queue	0.00
Seize c5d4.Queue	0.00
Seize c5d5.Queue	0.00
Seize c5d6.Queue	0.00
Seize c5d7.Queue	0.00
Seizec1d4.Queue	1.30
Seizec1d6.Queue	0.00
Seizec2.Queue	0.00
Seizec2d3.Queue	0.00
Seizec2d4.Queue	0.00
Seizec2d6.Queue	0.00
Seizec2d7.Queue	0.00
Seizec3.Queue	0.00
Seizec3d4.Queue	0.00
Seizec4d3.Queue	0.00
Seizec4d5.Queue	0.00
Seizec4d7.Queue	0.00
Seizec6.Queue	0.00
Seizec6d6.Queue	0.00

Decreased bottleneck queue waiting times