RESOURCE OPTIMISATION THROUGH CONSTRAINT MANAGEMENT AT MALAS DRIVESTYLE CENTRE

by

FIRDOUS TAYOB

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SUPERVISOR: Dr Olufemi Adetunji

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Executive Summary

Malas (Pty) Ltd, a retail and distribution company, has been engaged in the tyre industry for over three decades specializing in the supply of wheels and tyre products together with related services to the South African market. Due to the increase in export and domestic sales of automobiles, the South African tyre market is expected to witness phenomenal growth over the next couple of years.

The service centre, the Malas Drivestyle Centre houses a large and sophisticated workshop where its services are rendered. Currently it seems as if it is operating at full capacity, however, there is a great concern regarding the number of vehicles serviced per day. Management is of the opinion that maintaining current methods is hindering the company's ability to be able to satisfy the additional demand in order to remain competitive within the industry.

The entire service system is constrained by the activities of the Workshop thus, this project focuses on a capacity analysis of the Workshop. The analysis will identify and aim to remove bottlenecks present in the system as well as provide an efficient manner of re-allocating resources to ensure system performance and the throughput rate is improved.

After an investigation of Industrial Engineering tools, techniques and skills to solve capacity constrained systems was conducted, Simulation Modelling was selected as it is the best tool to accurately represent a real life complex system. The current As-Is model was modelled by the simulation, thus activities and resources were required to be analyzed in detail to construct the model as well as data analysis of real system data from the companies WMS system.

Scenarios were generated using OptQuest with the primary objective to maximize profit. Profit is a surrogate measure for the throughput rate. OptQuest automatically generates optimal scenarios with alternative resource configurations. Using the SMORE plots in Simio, the best performing alternatives which are statistically significantly similar to each other were identified.

These alternatives were recommended to Malas as a manner of planning and re-allocating their resources. By implementing this, not only is profits maximized but utilization of resources is inherently improved by the model. As a result the inefficiencies such as long queues and delays will be improved which results in increased customer satisfaction.

The project aims to deliver a model to the firm to act as a decision support system to aid in strategic future plans. Thus it is highly recommended to implement this solution to ensure the long term objectives of Malas are achieved.

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Chapter 1: Introduction

1.1 Background

Malas (Pty) Ltd, a retail and distribution company, has been engaged in the tyre industry for over three decades specializing in the supply of wheel and tyre products together with related services to the South African market. Due to the increase in export and domestic sales of automobiles, the South African tyre market and consequently, the tyre replacement market is expected to witness phenomenal growth over the next couple of years.

The Pretoria based facility, Malas Drivestyle Centre, is a multi-brand, multi-product automotive specialized fitment centre. It encompasses a modern showroom, convenient cashier points, a gourmet café, over 200 parking bays, a spacious office block, a large and sophisticated workshop (equipped with the latest equipment where the services are rendered) and a centralized warehouse facility equipped with conveyor systems and goods hoists linked to the receiving and dispatching areas.

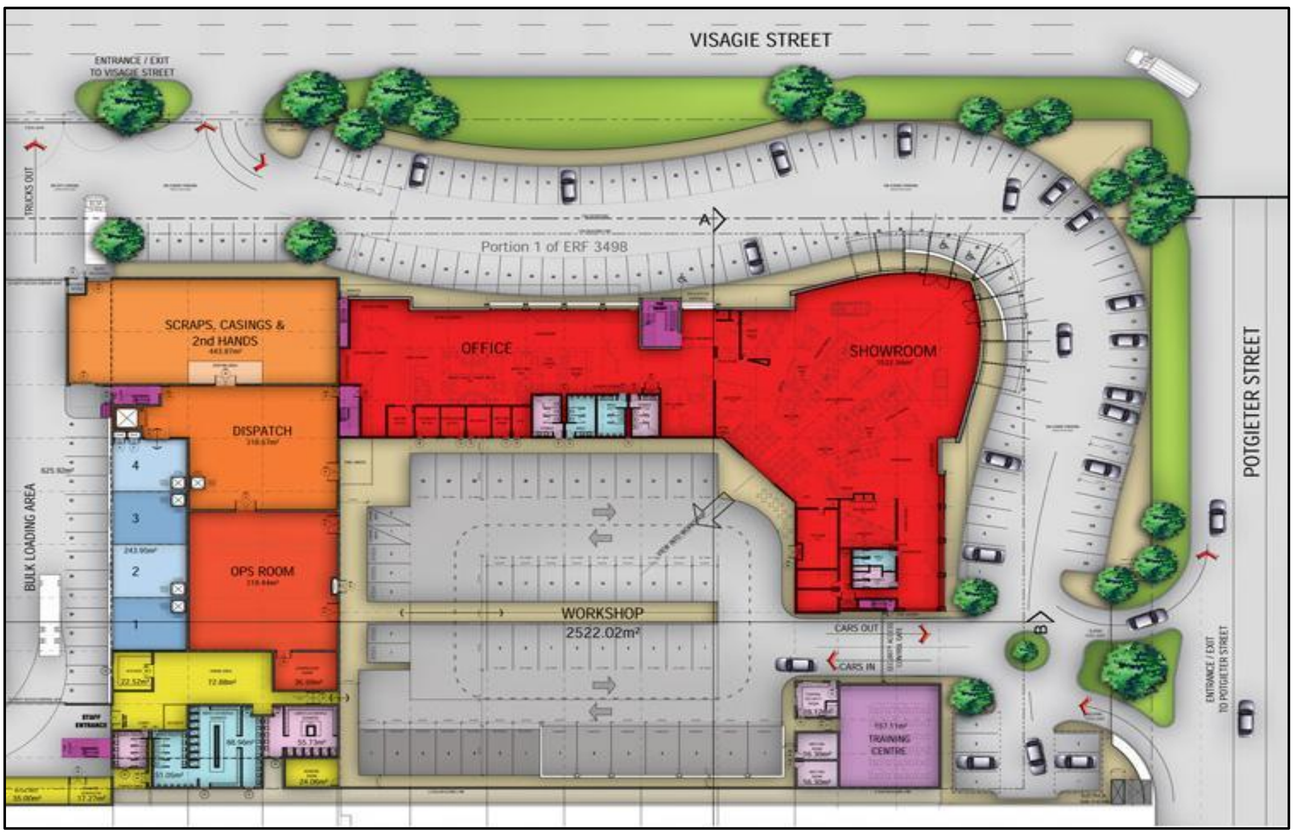


Figure 1: Malas Drivestyle Centre Facility

1.2 PRODUCTS & SERVICES

The products supplied covers an extensive range of tyres and wheels for motor vehicle applications as well as components such as brakes and shocks. Services include expert advice, tyre fitment, wheel balancing, wheel alignment and specialized fitment of the various component types. The service products can be grouped into the following categories: Wheel & Tyre Fitment and Balancing, Wheel Alignment, Undercarriage Services & Diagnostic Services.

WHEEL & TYRE FITMENT & BALANCING

Wheels and tyres are the main line of business at Malas. A customer may opt to purchase new tyres or wheels in which case the old tyre is stripped off of the wheel on the fitment machine, and then the new tyre is fit back onto the wheel using the same machine. Thereafter, the new wheel/tyre is balanced on the balancing machine and fit back onto the vehicle. If the customer chooses to simply balance his old tyres, the technician balances the old tyre/wheel using the balancing machine and fits it back onto the vehicle.

ALIGNMENT SERVICES

Alignment is purely a service and thus no products are involved. The bay is equipped with a computerized machine which the technician uses to render the service. Using the readings off the sensor placed under the tyres and the readings on the computer, the technician is able to do the alignment according to the vehicles specifications.

UNDERCARRIAGE SERVICES

This service includes the fitment of brake and shocks. The customer may choose to purchase new brakes or shocks or both in pairs only (for the front or back of the vehicle). The technician inspects the vehicle, removes the old parts and replaces it with the new parts.

TAKEOUT SERVICE

This applies to customers who opt to purchase products such as tyres or other parts but do not require them to be fit onto their vehicles. In this case, the customer places the order at the cashier and picks it up at the takeaway section of the Dispatch area, which is inside of the workshop.

DIAGNOSTIC SERVICES

Includes an inspection of the vehicle to identify the problems and provide expert advice as to what services are required. Initially, this was conducted inside of the workshop where six bays were allocated. However, it is now conducted outside of the workshop in the parking bay. Thus there are six extra bays available in the workshop, which are currently used as parking bays for small queues which form inside of the actual workshop.

1.3 The Workshop

The state-of-the-art facility houses over 50 bays and utilizes the latest and best technology and machinery available. The bays in the workshop are arranged and grouped together according to the categories above, comprising of Wheel/Tyre Fitment and Balancing bays, Wheel Alignment bays and Undercarriage bays. Each bay is equipped with the necessary tooling to conduct the services.

The workshop is manned by a workshop management team of a Workshop Manager, Gate Controller, Job Assigners and Quality Controllers. There is one technician allocated to a specific bay to render the services. The workshop is supported by a dispatch team consisting of a Dispatch Manager and Dispatchers for product management activities.

A centralized Operations Room exists in the workshop where installation and balancing activities are conducted It is equipped with tyre fitting/stripping machines and wheel balancing machines.

The Dispatch Area acts as a link between the warehouse and the workshop, when an order is processed the goods are picked and sent down to the dispatch area where the technician receives it. The ‘takeaway section’ is also located here for takeaway customers to pick up their orders.

Figure 2: The Workshop

1.4 Problem Statement

The major problems and delays experienced within the system can be attributed to the workshop processes. Even though the workshop is currently operating at full capacity, management are concerned that maintaining the current methods is hindering the company’s ability to satisfy a bigger demand for its services. The major area of concern directly relates to **the low throughput rate** currently experienced, i.e. the number of vehicles being serviced per day.

It is noted that the system is constrained by the activities of the workshop to achieve its goals to expand and deliver more. The problem is therefore viewed as a **constrained system problem**. The possible factors relating to these constraints within the workshop are:

1. Long queues at the workshop entrance (especially during peak hours)
2. Scheduling (including sequencing and job loading) of jobs to bays/technicians
3. Job flow completion rate within the workshop
4. Technician & machine utilization

Resources are shared between the different processes for the various types of services rendered in the workshop. Thus, these resources could be overloaded at times whilst others could remain idle. The bottlenecks in the system are the cause for limiting throughput and therefore must be identified and improved.

CAPACITY CONSTRAINED SYSTEM

Malas offers a wide range of different services to remain competitive and due to this, managing the problem becomes complex. Customers may opt to choose one or more different types of services. Complexities arise as the length of time for each service is stochastic depending on the (1) type of service, (2) type of products required, (3) the number of tyres/parts being serviced and (4) unavailability of products in the warehouse. Thus technicians are not immediately available, causing delays. Some services and activities are dependent on others which adds to the problem and further, if a problem is identified by the technician an extra service might be required.

As described by Siha (1999), an unpredictable environment is created due to the interaction of stochastic service times, dependent service activities, probabilistic service packages, frequently occurring bottlenecks and consequently, scheduling becomes difficult.

The problems attributed to the workshop system can be classified as a **capacity constrained system**. Managing capacity and constrained resources must be further investigated as to how they are solved in practice.

1.5 PROJECT AIM

The aim of this project is to identify and manage the constraints present within the workshop system in order to improve the workflow rates, to ensure the workshop capacity is optimized and utilized to its fully possible extent. This will be done with the intention of achieving the firm’s main objective, to increase the throughput rate i.e. the number of vehicles serviced per day.

A model representing the real life system will be developed through the use of Industrial Engineering techniques such as mathematical or simulation modeling. The most efficient way of re-allocating resources will be identified in order to maximize utilization whilst reducing inefficiencies currently present in the system. This will be done by evaluating alternative configurations of resources and comparing each scenario to the base case model.

Recommendations will be made as to how the resources of the workshop are to be planned and scheduled in order for the firm to achieve its objectives and maximize their profits.

1.6 PROJECT APPROACH, SCOPE & DELIVERABLES

The project approach to achieve the desired outcomes is broken down into six phases as illustrated below.

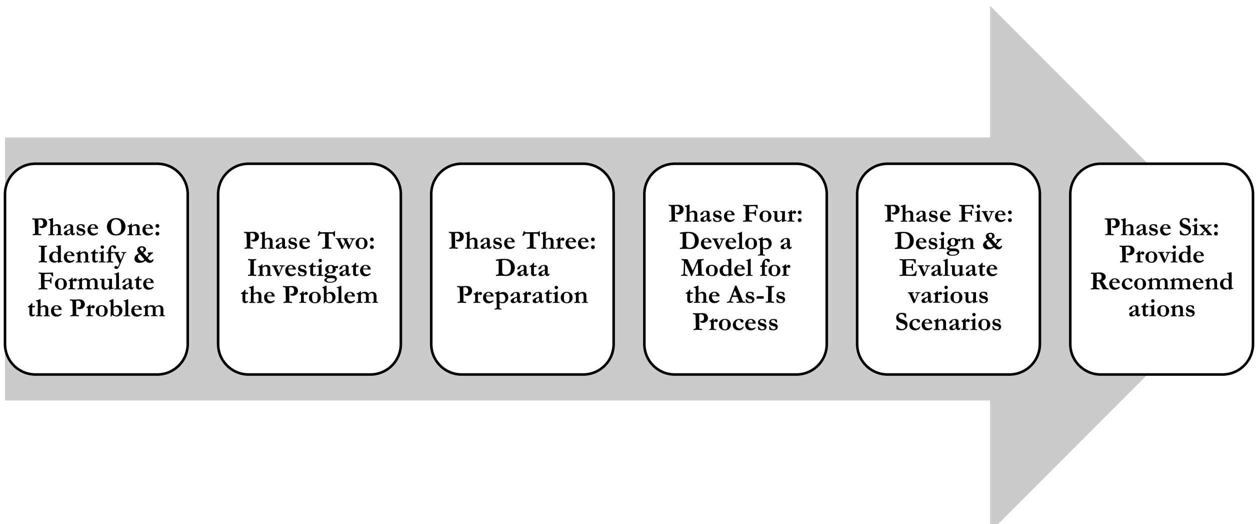


Figure 3: Project Approach

PROJECT SCOPE

The project will be conducted at the Malas Drivestyle Centre, based in Pretoria. The scope will be limited to the service operations of the Workshop only and thus exclude the customer sales and payment process. Since Diagnostic Inspections are now conducted outside of the actual workshop, it is excluded from the scope of this project. In order to manage the constraining system, problems may arise within the supply chain system as well as the operations of the warehouse, which will be excluded from the scope of this project.

DELIVERABLES

The project intends to deliver a Workshop Solution which includes the following:

1. a model representing the real life As-Is process;
2. identification of bottlenecks and capacity constrained resources;
3. the design and Evaluation of various scenarios;
4. a recommendation of how to plan and reschedule resources
5. a final detailed project report; and
6. a final project presentation.

Chapter 2: Literature Review

2.1 Introduction

Research is conducted to investigate the most appropriate IE techniques available to solve problems and achieve the objectives of the workshop. Literature is reviewed to fully understand the nature of the problem and case studies pertaining to how other companies with similar scenarios have approached the situation are studied. The outcomes of these techniques used in practice are analyzed to be able to select the most appropriate alternative.

2.2 Capacity Management

Capacity Management can be defined as managing the limitations of a company's resources to ensure operations run smoothly. Wanliss (2009) indicates that Thacker (2009) stated capacity planning includes the creation of "sufficient, flexible, capable capacity and a valid, best 'do-able' resilient plan to accommodate demand." Gademan and Schuten (2005) state: "Many multi-project organizations are capacity driven, which means that their operations are constrained by various scarce resources." They advance that capacity planning can be described as aiming to balance demand and availability for resources for the medium term. Armistead and Clark (1994) mentioned: "There is an interaction between capacity management, quality management, and resource productivity or efficiency management which is at the heart of the planning and control process for operations management."

If the capacity of a service is increased, queues and waiting times will decrease however this might lead to servers becoming idle at times, thus the problem is to manage the tradeoff between idle capacity and delays. As Beasley (2009) discusses issues related to assessing performance of a system are:

- How long is the expected waiting time in a queue for a customer before he is served and how long does it take to complete the service?
- What is the utilization of the server and the expected time period that he is not idle?

Problems which management should address are:

- Is it worth investing in additional resources to reduce the service time?
- What is the number of servers required?
- Should priorities for some customers be implemented?

There are two approaches to manage the issues highlighted above:

1. Analytical Methods (Mathematical Programming & Heuristics) or the Queuing Theory which are formula related; and
2. Simulation Modeling which is computer based.

The first approach is ideal for simple queues and systems whilst simulation is used widely for complex systems.

CAPACITY MANAGEMENT CASE STUDIES

Capacity management is implemented in many different sectors using various techniques.

A study originating from a machine scheduling problem by Zhang, Cai and Wong (2002) is conducted on a resource constraining schedule problem where a number of jobs can be produced on a single machine (multiple-job-on-one-processor) simultaneously in parallel without exceeding the capacity of the machine. The objective is to minimize the total time of the jobs. An existing mathematical algorithm is analyzed and improved to obtain the objective subject to the capacity constraints. This mathematical model has applications in situations where the different activities require different amount of resources and have a different processing time for the allocated resource which is limited.

A model to manage capacity by Gademan and Schuten (2005) using linear programming based-heuristics was developed. The capacity planning model includes capacity flexibility, relationships between work packages and the maximum work content per period. This model can be applied to capacity driven multi project organizations.

Atwater and Chakravorty (2002) investigated the utilization of a capacity constrained resource in Drum-Buffer- Rope system by testing changes of the two most heavily utilized resources on the DBR schedule system. They state: “Goldratt, the originator of the Theory of Constraints (TOC), maintains that only the system's primary resource constraint should be scheduled at 100% of capacity. All other resources should have excess capacity.” He indicates that the excess capacity is called ‘protective capacity,’ because the system relies on the extra capacity to minimize problems to ensure the constraint remains on schedule and orders are processed on time. The study addresses the following issue: the system’s primary constraint is unrealistic in practice to be operated 100% of the time thus what range of utilization on the CCR makes DBR performance maximum with respect to Manufacturing Flow time. Simulation Modeling was used to investigate the effects.

In an article presented by Starks, Creces and Schwieters (2006), a dynamic decision tool was required by Dafasco regarding its operations in the steelmaking sector. Using Rockwell’s simulation software Arena, system bottlenecks were identified, throughput was increased by using resources more efficiently and the proposed system was analyzed and fully understood before investing in additional capital to implement it. “The aim of the model was to validate the assumption that the process was capable of achieving its yearly production goal.” The first step included documenting the process by defining system processes in detail to compile specifications and process flows. The next step was the model construction where process times, decision probabilities and failure parameters for all resources were collected and stochastic distributions were fitted to process delays and resource failures. The scenarios were constructed to test what was constraining the output potential for the system and to validate whether changes in sub-processes improves productivity.

Smit (2012) used a simulation model to determine the optimum number of resources to be allocated to the auditing area of a warehouse which was identified as the system’s bottleneck. The model aimed to improve efficiency, increase the throughput and minimize overtime costs. Similarly, Putter (2009) developed a simulation model using Arena to investigate alternative resource configurations to increase productivity of a capturing process for a small paperwork execution company in order to maximize the number of boxes processed per day.

The above mentioned case studies provides insight into what capacity management is and the various techniques used to implement it. Capacity management originated and is widely used within the manufacturing sector. However, the service sector is distinct from the manufacturing sector as a service cannot be produced in advance and held in inventory and thus certain techniques must be altered to make it appropriate for a service organization. Since Malas operates within the service sector, literature specific to this sector must be studied to understand what techniques are used to manage capacity constrained systems in a service environment.

CAPACITY MANAGEMENT IN THE SERVICE SECTOR

"Capacity management in services to match supply and demand has a direct influence on the ability of the service delivery system to achieve service quality and resource productivity targets." (Armistead & Clark, 1991)

Armistead and Clark indicate that capacity in a service environment is defined as "the ability to work off an existing demand." It has a time dimension and is linked to an output quantity. They highlight the idea that due to the wide range and mix of services offered, variation occurs which indicates the capacity of the system will change if the balance of resources are altered.

2.3 THEORY OF CONSTRAINTS

The Theory of Constraints, developed by E.M Goldratt, is a management philosophy which states "a system's constraint is anything that limits a system from achieving higher performance versus its goal." Siha (1999) says: "System constraint is the heart of Theory of Constraints." Goldratt says that TOC aims to ensure daily operation's performance is maximized through driving the system's constraints/bottlenecks and long term performance is continuously improved.

According to Siha, TOC can be applied to daily operations as well as continuous improvement. Daily logistics operations can be managed through performance measurements and the scheduling process. Three performance indicators are mentioned by Goldratt and Cox (1992) namely: throughput (T), inventory (I) & operating expense (OE). The aim is to increase T whilst reducing I and OE. Scheduling includes the Drum, Buffer Rope approach which aims to ensure constraints are operating at its highest capacity to obtain maximum performance. She goes on to explain that the drum represents the rate at which the constraint resource processes, the buffer is measured in time to ensure the flow of the process is prioritized whereas the rope is a link to the drum to ensure the right amount of work is always maintained.

Continuous improvement can be done using The Five Steps Focusing process:

1. Identify the System's Constraints
2. Decide How to Exploit the System's Constraints
3. Subordinate Everything Else to the Above Decision
4. Elevate the System's Constraints
5. If in the Previous Steps a Constraint Has Been Broken, Go Back to Step 1 but do not allow inertia to cause a system constraint

Badri and Aryanezhad (2010) mentions: The goal of theory of constraints (TOC) is to maximize output, which is achieved by identifying and managing the critically constrained resources." Step Four in particular of the 5FS is used. They describes step four as: if constraints are critical, improvement of them will improve the system performance and the potential of non-constraints is known. "Eventually the system will encounter a new constraint." Goldratt presented an algorithm to solve product mix problems to maximize profit however it was not able to provide an optimal solution for multi constrained resource problems. Thus TOC together with a heuristic mathematic algorithm was developed and the objective function for the optimization problem is to maximize the CCR output.

2.4 The Queuing Theory

Zhao, Hou and Gilbert (2014) indicate that waiting lines and delays have become common in the service sector and thus managing waiting times efficiently to ensure services are delivered on time enhance the customer experience which can be used as a competitive strategy.

Winston (2004) describes the queuing theory, developed by Erlang, as an Operations Research technique to manage waiting lines/queues by providing insight into the queue and waiting times. Beasley (2009) mentions that a queue can be described by an arrival process as to whether customers arrive single or in bulk, the inter-arrival time distributions and whether there is a finite population of customers or infinite. It is also described by the server mechanism (independent of the number of customers present) which is a description for the resources required to complete the service, the process time and the number of servers available. To fully describe a queuing system would be to describe how the customer joins the queue, the queue discipline. The rule used by Malas is the FCFS discipline where customers are served in the order they arrive in.

Vohra, Dutta and Ghosh (2006) have developed a queuing model to efficiently manage the capacity of Intensive Care Units in a multi-specialty hospital where alternative ICUs are utilized if the standard ICUs are full due to the heavy patient overload. It includes utilizing resources such as doctors, nurses, equipment and beds optimally. Each ICU is represented as a service station and each bed a server. The project goals were to obtain steady state queuing models and to obtain expected number of patients in the system. The input data included average arrival rate per day, arrival patterns, service time (length of stay) and distribution of the service times. The objective of the queuing model was to maximize the number of patients served in the system. The results of the model indicate that utilization increased up to 28% and admitting patients into alternative ICUs was recommended. However, the model includes 19800 steady state equations which are solved through an optimization solver software. This model can be even more complex when many type of server stations and servers are involved.

2.5 Mathematical Modeling

Operations research includes analytical methods to manage systems and typically is involved with the planning and allocation of scarce or constrained resources. The system is represented by an algebraic model which is solved through mathematical methodologies to provide optimal solutions. Linear programming provides an objective function which may be maximized or minimized and is limited by certain constraints present. In the Workshop problem, the objective function would be to maximize the throughput rate.

In a case study by Ahmadi (1996), capacity problems of the rides at a theme park, Six Flags Magic Mountain is studied in terms of daily operations with the aim of finding an optimal solution for the ride's nominal capacity. Poor management leads to undesirable customer waiting or under-utilization of the resource capacities Similar to the Malas Workshop, the service packages is non-homogenous, customer preference is not uniform and attendance level fluctuates according to the day or season. Capacity can be changed by increase or decrease of the number of operating units for each ride. The Capacity Management Model used visitor arrival pattern to the ride, transition patterns in the park, and the rides' observed capacity to determine the most optimal nominal capacity level for the rides at different times. The objective is to maximize park service level (throughput rate). The constraints limit the objective and they include operating budget, customer threshold value for number of rides and maximum allowable length at the rides. The CMM model is a mixed integer linear problem.

2.6 Simulation Modeling

Chase et al. (2004) discusses that simulation is defined as the technique that imitates the operation of a real-world system as it evolves over time. It is used for capacity planning, resource requirements, analysis of waiting lines and schedule of operations in the service sector. It is appropriate for situations of great complexity where analytical or optimizing tools are difficult. He says: "Often when a mathematical technique fails we turn to simulation."

A schematic diagram of a simulation study is illustrated in Figure 4 below. (Maria, 1997)

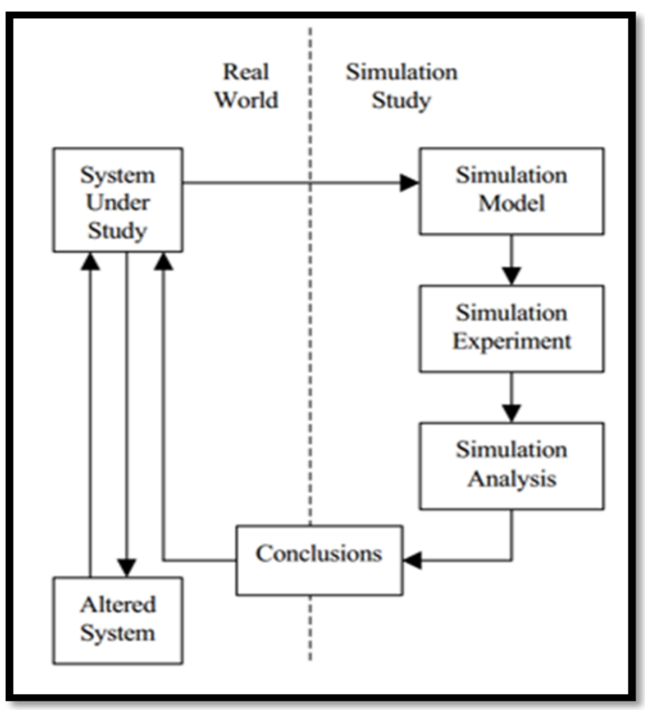


Figure 4: Simulation Study Diagram

SIMULATION MODELING CASE STUDIES IN THE SERVICE SECTOR

Kuhl et al. (2005) suggest that discrete event simulation is a tool used to evaluate process flows and bottlenecks, throughputs and delays as well as capacities. They advance, it is used widely in the service sector such as call centres or hospitals and also for theme parks, health sector, ambulance systems, parking management and evacuation systems. They suggest the idea of SimOr which is a combination of Simulation for evaluation purposes and OR for its optimization.

Geng and Cassandras (2011) use Integer Programing and Simulation for a dynamic resource allocation approach for a “smart parking” system. An objective function includes parking cost and distance proximity, whilst ensuring capacity utilization is maximized for the system to optimally reserve a parking space called the resource for a driver.

Lin (2013) conducted a study to increase patient flow and capacity for an eye outpatient department in Hong Kong using computer simulation to serve as a decision support. The model aims to identify bottlenecks with regards to layout changes, patient scheduling and the resource allocation plan. Further, to determine congestion in terms of performance measurement for the multi-phase queuing system serving different classes of patients with different sequences. Lastly, to test scenarios to increase throughput, service capacity of patient per quota and to ensure hospital management understand and identify the room for improvement. The ‘decision support simulator’ can be used as an evaluation and planning tool to measure performance for future changes.

De Wet (2010) focuses on capacity analysis of the Lanseria International Airport’s land and airside due to the increase in passenger demand. It includes investigating what the optimal number of aircraft operations is during peak times subject to minimizing delays and congestion in the airport terminal. An Arena simulation model representing the complex system was constructed and scenarios were tested to address and eliminate bottlenecks. The objective was to determine what the maximum capacity is in terms of the number of passengers that may be processed and the number of aircraft operations that may be conducted and these solutions may serve as a decision tool for strategic planning. (De Wet, 2010)

ADVANTAGES AND DISADVANTAGES

Chase and Jacobs (2011) discuss the following:

Advantages of simulation include a better understanding of the real system through a model, compression of time (years can be expressed in seconds), provides a realistic representation of the real system and can be custom built to replicate the real system, may analyze transient conditions unlike mathematical models and may answer ‘what-if’ questions.

Disadvantages include a lack of standardized approach to construct models, constructing a complex model may take very long, in some cases there is no guarantee that a simulation model will provide accurate answers due to it being based on random variables unlike a mathematical model.

SIMULATION SOFTWARE

Arena

Rockwell's Software, Arena allows one to easily account for the stochastic (variable and random) nature of processes. True system behavior may be emulated by utilizing statistical distributions that the processes and systems have shown to mimic through distribution curve fitting. The simulation can then randomly sample those distributions to create events into the system (e.g., customer arrival, failure events, etc.) or the duration of an individual event (e.g., process time, failure downtime, etc.). These events are then "scheduled," allowing the user to watch how the system performs over time. The power of simulation lets one account for these event interactions and evaluate what effect these events and interaction of events have on the true performance of the system.

Arena models are built using a flowchart style, process orientation approach to build and run simulation models where building blocks are used to build the process flow. Elements must be defined to determine the state of the system and entities must be created which move from block to the next over time.

Simio

"Simio is a tool for building and executing dynamic models of systems so that one can see how they perform." (Pegden, 2012)

He goes on to describe that Simio is much easier to use than other software due to its object-based approach where objects represent real components of the system and a 3D animation may be viewed. A wide range of systems from health care to mining, to supply chain may be modeled. The idea is to have model entities such as trucks, patients or customers move through the system which is constrained by resources such as machines, doctors or pathways. The flow of the entities through the system is modeled.

In terms of analysis of results, experiments can be created where specific inputs are altered to examine changes in performance. Simio provides an easy way of setting up and running experiments through the use of add-ons such as OptQuest.

2.7 Literature Review Conclusion

Various Industrial techniques were identified from case studies pertaining to capacity constrained systems, particularly within the service sector.

The Queuing Theory case study was similar to the Malas Workshop scenario however there was a large number of steady-state equations and when many different types of servers are involved for a variety of services offered, this model becomes even more complex. And further this method may prove not to be appropriate as the Workshop system may not be in a steady state condition. Lastly, as mentioned by Kelton (2007) problems associated with the queuing theory are that the natural or inherent variability of a system are not included in the formulas and the arrival & service rates are not an exact estimate.

Chase *et al.* (2006) mentioned: "Mathematical analysis, when appropriate to a specific problem tends to be fast and inexpensive, but the only real question is whether the system is accurately represented.".

This can be a problem due to the fact that the workshop includes many different types of resources where capacity needs to be planned and the activities to carry out the service share these resources. Thus, this system may be too complex to be model accurately and mathematical modeling may not be the best option to solve -the workshop problem.

“Even though mathematical models are faster and less expensive, simulation has no boundaries and expanding computer power and memory have exceed the limits of what can be simulated. The continuous development of simulation languages, such as SIMAN or SLAM and specialized software such as SIMFACTORY or Optima! have made the entire process of simulation models much easier.” (Chase *et al.*)

From the literature review, simulation modelling proves to be the best alternative from the selection of techniques to manage the capacity constrained system present at the Malas Workshop. Due to the complex system of the workshop, the wide variety of services offered and the large number of resources which are shared by processes, simulation will be the best tool to accurately represent the real life system.

Chapter 3: Conceptual Design

3.1 SIMULATION MODEL DEVELOPMENT

The project approach will follow a simulation methodology as discussed by Maria (1997), which includes the following steps.

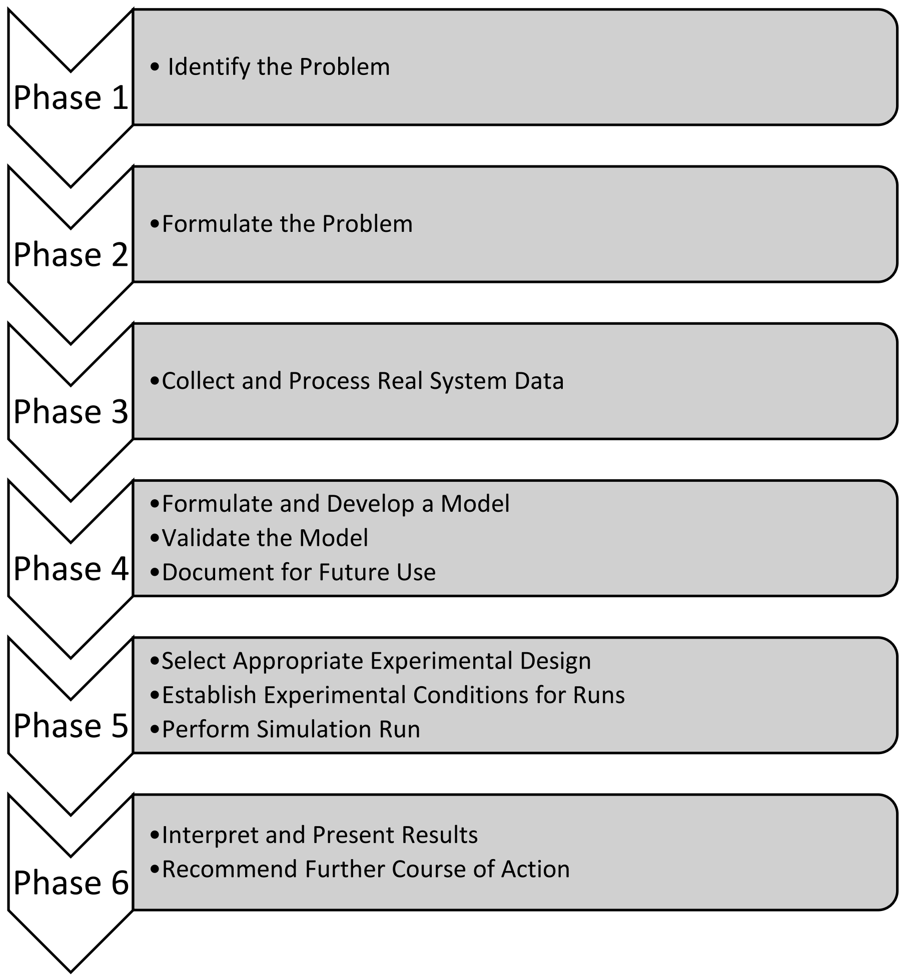


Figure 5: Simulation Methodology

1. Identify the problem: Identify problems in the workshop system and identify requirements for the proposed system.

2. Formulate the problem: Select the problem scope, objectives and performance measures. Investigate the techniques used to solve the defined problem in practice.

3. Collect and process real system data: Input variables, performance of the system and other necessary data must be collected from data available on the company's database. Probabilistic distributions must be fit to stochastic input variables.

4. Formulate and develop a model: Flow diagrams for the high and low-level processes and schematics are drawn up in the conceptual design to be translated to a form suitable for the simulation software. Verification must be conducted which includes using a range of input values to test the outputs by using constants instead of random values to manually verify the result to ensure errors do not exist.

5. Validate the model: Validation means to run the model and compare the performance and results to the real system to ensure assumptions in the model are valid and consistent.

6. Document for future use: Goals, objectives, assumptions and variables must be recorded.

7. Select appropriate experimental design: Experiments involve making changes to input variables specifically the workshop resources, to determine how the performance is altered. Performance measures and specific inputs are selected as well as the levels for each one. These scenarios are designed to test the effect of different resource allocations on the performance and throughput rate of the system.

8. Establish experimental conditions for runs: The aim is to obtain accurate and the most information from one run, understand if the system changes over time(non-stationary) or not (stationary), should the run be terminating or non-terminating, allocate the run length, select the starting conditions and warm up period if necessary and the number of independent runs.

9. Perform simulation run: Run the model according to the conditions in the previous step.

10. Interpret and present results: Most software include statistics on certain measures such as waiting time, queue length or utilization etc. Hypotheses can be tested regarding the performance, animation of the outputs may be illustrated and results must be documented. The results are analyzed to determine how to re-allocate the resources to its best possible extent to ensure the throughput is increased.

11. Recommend further course of action: Provide suggestions and recommendations as to how to solve the problem to Malas and possibly more experiments to reduce bias, other performance measures or modifications for future plans and improvement.

3.2 Simio

Using the simulation software package, Simio, the simulation model is constructed to represent the As-Is processes of the workshop. A standard object library is provided by Simio, which are the ‘building blocks’ for model construction. These objects can be used to: process, create, transport or destroy entities that mimic real world processes. (Simio, 2010)

Name	Description
Source	Creates entities that arrive to the system
Sink	Destroys entities and records statistics
Server	Models a multi- channel service process with input/output queues
Combiner	Combines entities in batches
Separator	Separates entities from batches
Work Station	Models a 3-phase workstation with setup, processing and teardown
Resource	Models a resource that can be used by other objects
Vehicle	Carries entities between fixed objects
Basic Node	A simple intersection of links
Transfer Node	An intersection where entities set destination and wait on transporters
Connector	A zero-time connection between two nodes
Path	A pathway between two nodes where entities travel based on speed
Time Path	A pathway with a specified time travel
Conveyer	An accumulating/non-accumulating conveyer device

Table 1: Simio Standard Object Library

3.3 As-Is Process Analysis

Before building a model to represent the real life system, the processes which are conducted in the workshop to render services need to be studied and thoroughly understood. Thus, process flow diagrams are constructed to identify the flow of objects and information within the workshop. The processes will be directly translated and modeled in Simio.

The process is constructed by individual activities and delays. The table depicts the symbols used in the process flow charts.

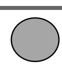
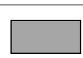
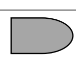
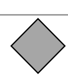
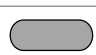
Type	Symbol
Start	
Activity	
Delay	
Decision	
Terminate	

Table 2: Process Flow Symbols

Activities include seizing one or more resources to complete the activity and then releasing it when it is done. This is done using the unique capability in Simio called Add-On processes in which the objects can be customized to suit the system. Delays are also modeled with the use of Add On processes.

Both activities and delays, require a time inputs to be built into the model which is obtained from the company's database. The Input Analyzer from Rockwell's software Arena, will be used to fit statistical distributions to the data.

The Decision box implies that different options are available and this may be due to a probability chance or by a condition, which is also modeled in Simio by using add-on processes.

3.3.1 High Level Process Flow Diagram

Arrival of Vehicles

After a customer makes a payment for his order, an invoice is processed. A job card is provided to the customer, and a picking slip is automatically sent to the warehouse for the items to be picked. Thereafter, the customer drives his vehicle to the workshop where he joins a single queue at the entrance, irrespective of the service type required. Once he is allowed access by the Gate Keeper, the Job Assigner assigns him to a bay.

Job Scheduling

Jobs are assigned to the first available bay on a First Come First Serve basis. If there are more than one services required for a vehicle, the service which is the first to have a vacant bay will be completed first. Once the first service is complete, the Job Assigner re-assigns the vehicle to the next vacant bay for the next service to be complete. As a result, smaller queues may form within the actual workshop itself. The following rules for job scheduling are pointed out:

- A vehicle already present in the workshop has preference to a vehicle in the queue outside of the workshop.
- If Tyre Fitment is required, Wheel balancing becomes obligatory.
- Wheel Balancing must always be conducted directly after the Tyre Fitment Process
- If an Undercarriage service is conducted, Wheel Alignment is obligatory.
- Alignment must always be done after the Undercarriage service. However, other services may be rendered in between them.

It is noted that when the Job Assigner assigns a vehicle to a bay, a technician is automatically assigned to the vehicle as well. One technician is required to complete one job.

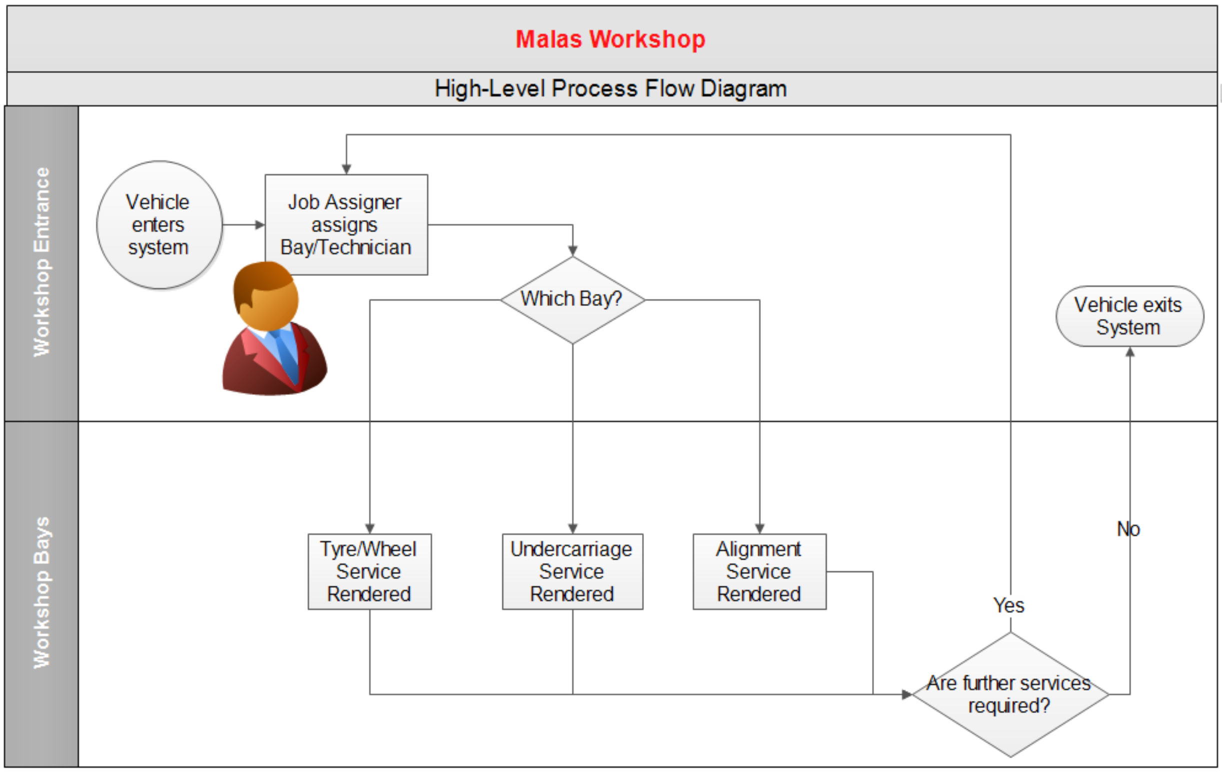


Figure 6: High Level Process Flow Diagram

3.3.2 Low-Level Process Flow Diagrams

3.3.2.1 Tyre & Wheel Fitment and Balancing Process

For Tyre Fitment & Wheel balancing, customer may choose to service between one and four tyres/wheels. New tyres, new wheels or both may be purchased. Further, the customer may not require new products at all and simply requires the old wheels to be balanced.

Once the vehicle is assigned to a bay, the technician directs and lifts the vehicle onto the bay. After inspection, the tyres are removed and moved to the Ops Room. Using one of the Fitting Machines, the tyres are stripped off the wheels. The technician proceeds to the Dispatch Area where he provides a job card to the dispatcher to receive the goods. After obtaining approval by the manager, the goods are released. The technician moves the new wheels/tyres back to the Ops rooms where he fits them on using the same fitment machine. Thereafter, he proceeds to the balancing machine to balance the new wheels. Lastly, the new wheels/tyres are fit back onto the vehicle.

If Wheel Balancing only is required, the fitment machine sub-process as well as the dispatch sub-process are excluded since there is no new goods purchased. The technician simply balances the old wheels using the balancing machine and the rest is the same as described above.

After approval from the Quality Controller, the job is complete and the vehicle may exit the bay. If it is not approved, the technician must rework and fix the errors. A quality check must be conducted again and if approved, the job is complete and the technician and bay is available for a new job.

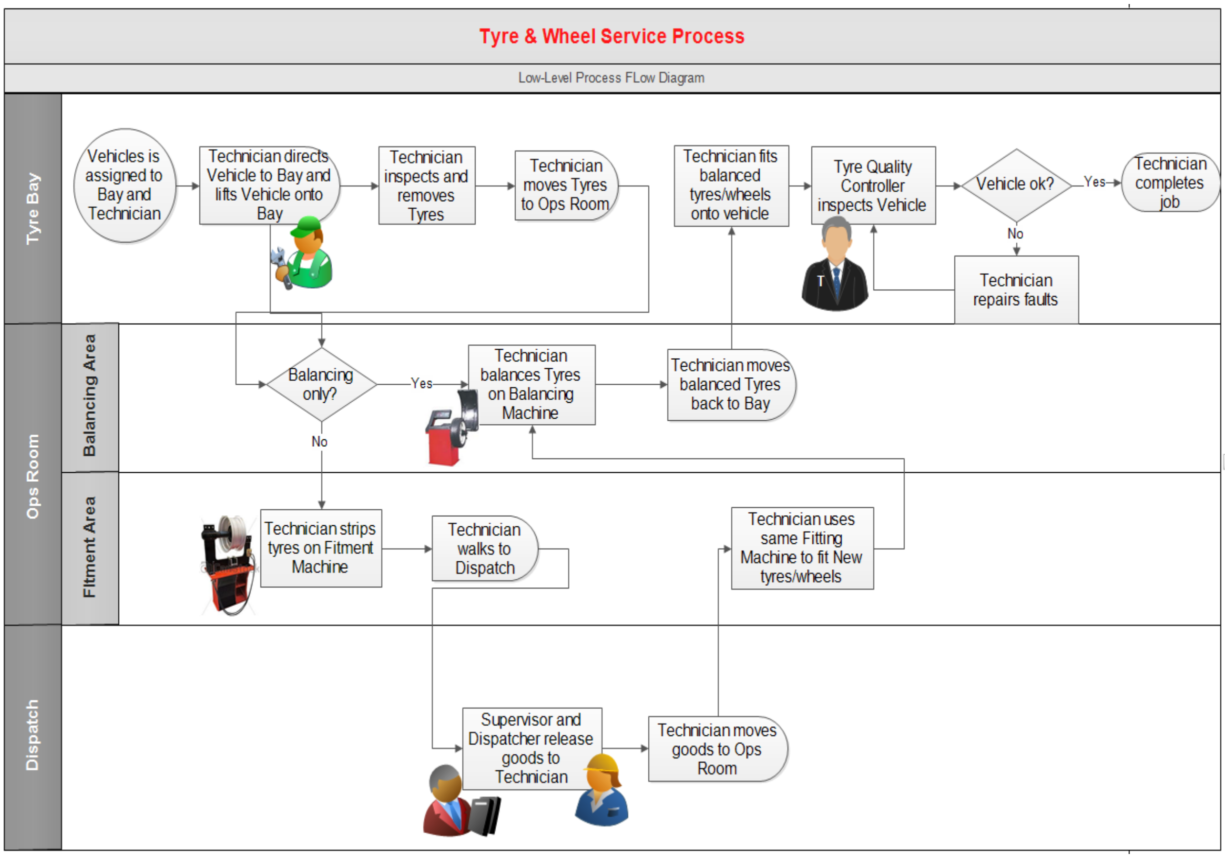


Figure 7: Tyre Fitment/Balancing Process Flow Diagram

3.3.2.2 Undercarriage Service Process

Customer may opt to service their vehicle's shocks, brake pads or both. The parts may be purchased in pairs only, which is for the front and the back of the vehicle.

Similar to the Tyre Fitment/Balancing process, once a job is assigned, the technician directs and lifts the vehicle onto the bay. After an inspection, the parts required are removed. The technician proceeds to the Dispatch area to receive the goods. Parts are not stored in the actual warehouse due to the wide variety required for various vehicles, space constraints and the fact that only a small percentage of customers require this service. Parts are ordered multiple times on a daily basis when required and thus this process can be quite lengthy due to delays in waiting for the part to arrive at the dispatch. The dispatch sub-process is conducted in the same manner as the tyre process. These deliveries are carried out daily, and thus there are long delays associate with this service. However, only a small percentage of vehicles require undercarriage services.

Once the goods are released to him, he fits the parts onto the vehicle and the quality checks are conducted. After approval, the job is complete and the vehicle may exit the bay.

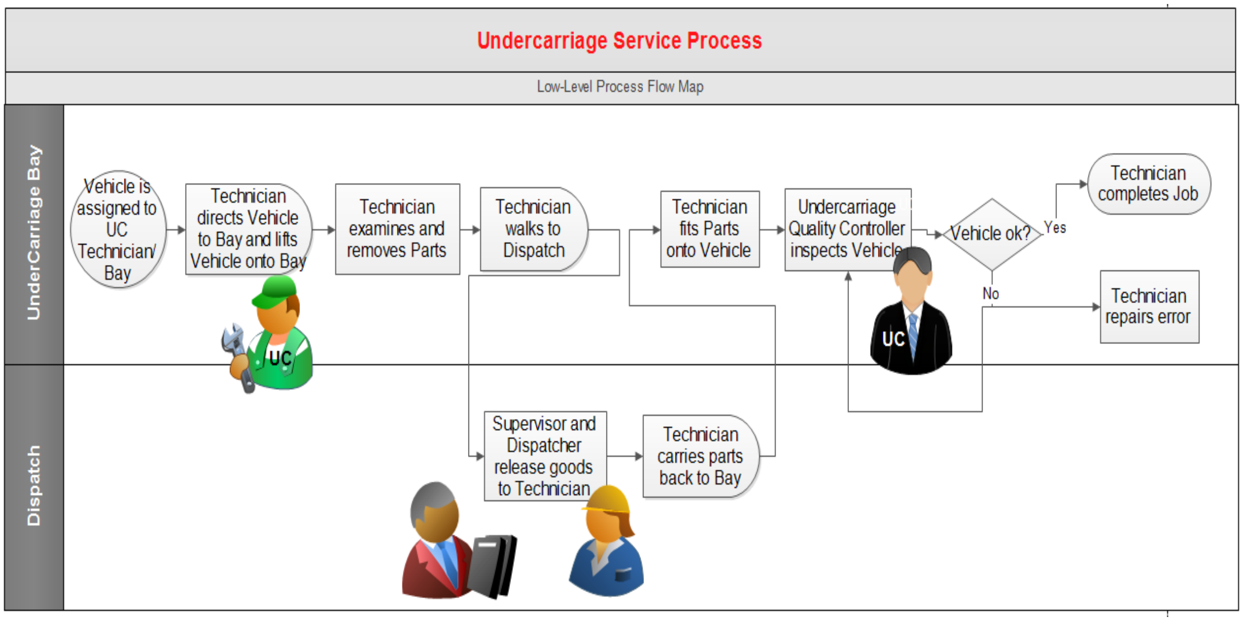


Figure 8: Undercarriage Process Flow Diagram

3.3.2.3 Alignment Service Process

The alignment process is purely a service and thus no dispatch activities are involved. Similarly, once the job is assigned, the technician directs and lifts the vehicle onto the bay. The bay is equipped with a built in machine to render the alignment. Using readings from a computer and sensors placed underneath the vehicle, the technician may accurately align the wheels according to the vehicle specifications.

The quality checks are completed and after approval, the job is complete.

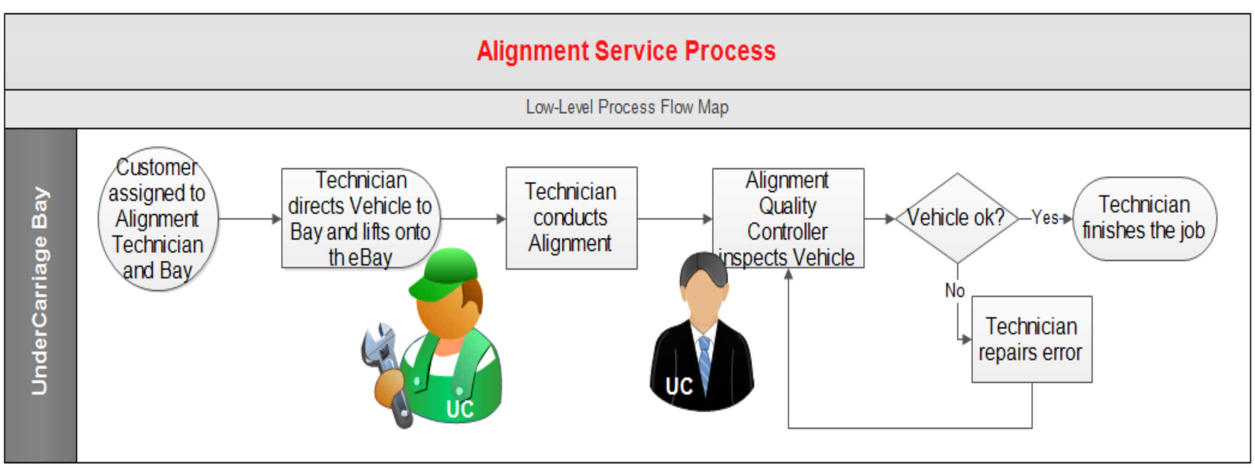


Figure 9: Alignment Process Flow Diagram

3.3.2.4 Takeaway Service

Lastly, the takeaway customer process must also be included as it shares the same dispatch area as that of the workshop. When a customer purchases wheels, tyres or parts, an invoice is generated and a picking slip is sent to the warehouse. The customer proceeds to the takeaway section of the Dispatch Area where the dispatchers obtain the order. After approval from the manger, the order is released to the customer who then exits the system.

3.4 Translation to Simio

The high and low level processes are directly translated into Simio to construct the model. A source object is used to generate the vehicle and takeaway customer entities. The vehicle entities are assigned with attributes to determine which services it requires. Each service process described above are modeled using the server object in Simio which acts as a process as well as a resource. Once the entities have specific attributes, routing logic enables the entity to move through all the required servers once. Thereafter, they move to a sink object which destroys entities and records statistics such as the throughput rate.

Technicians, Dispatchers, Quality Controllers, the Job Assigner and Dispatch Manager are modeled as worker objects. The Fitment and Balancing Machines are modeled as resource objects. Their respective capacities are allocated to represent the real life system.

Each server namely; Tyre Process, Undercarriage Process and Alignment Process will be given a capacity to allocate the number of bays there is available for each. Add-on processes will be used to explicitly model the individual processes described above. Seize and Release objects are used to seize the resources and release them once their activity is complete. Delay objects are used to model each individual activity in the processes and thus the total processing time is a sum of the individual delays. The Alignment process is an exception to this since there is only one individual process involved.

The workshop will be modeled as described above to represent the individual components which make up the system. The model construction will be discussed in further detail in Chapter 5.

The next step is to obtain input variables to be built into the model. Inputs include entity arrival times, process and delay times, service type probabilities, resources capacities as well as cost/revenue factors. This is discussed in the following section, Chapter 4.

Chapter 4: Data Analysis

4.1 Data Collection

Input data modeling is a critical component of a successful simulation application. Input variables such as resource capacities, arrival rates, process and delay times as well as cost/revenue factors must be built into the model during construction, to accurately represent the real life system. Thus, real system data must be collected and processed.

The company uses a system called the Workshop Management System which is a custom developed, web-based system designed to manage the job allocations in the workshop. Once an invoice is generated in the ERP system, it is integrated into the WMS database. Further, it collects information such as customer name, registration number, time vehicle entered, time job is started, time job is complete, service type, number of products etc. The data field are mapped into the respective columns in the WMS database where it is stored.

The data, for a few months in 2014 was extracted from the WMS was into Microsoft Excel, where it was sorted and organized. In the case where an expression for the distribution of the data was required, the Input Analyzer was used to fit statistical distributions to the data. For other purposes such as obtaining probabilities, Microsoft Excel was used. A screenshot of the Excel Spreadsheet is made available in Appendix B.

For the processes which are modeled explicitly as individual activities or delays, data is not available from the database and therefore interviews with the workshop manager were conducted to obtain the information required. Statistical distributions which were most applicable to the nature of the specific input were used to obtain very close estimates.

4.2 Resource Capacities

In Simio, a resource is a generic object such as workers or machines which is seized and then released by other objects. From an interview with the workshop manager, the types of resources in the system, the capacity for each type of resource and the number of each type of resource to be seized to complete one job were obtained.

Resource Type	Resource	Capacity	No. seized per Job
Workshop Management Team	Gatekeeper	**1**	1
	Job Assigner	**1**	1
	Tyre/Wheel Quality Controller	**1**	1
	Undercarriage Quality Controller	**1**	1
	Alignment Quality Controller	**3**	1
Dispatch Team	Dispatch Manager	**1**	1
	Dispatchers	**3**	1
Technicians	Tyre Technicians	**32**	1
	Undercarriage Technicians	**5**	1
	Alignment Technicians	**7**	1
Bays	Tyre Bays	**32**	1
	Undercarriage Bays	**5**	1
	Alignment Bays	**7**	1
Operations Room	Fitting Machine	**16**	1
	Stripping Machine	**16**	1

Table 3: Resource Capacities

4.3 Entity Arrival

Two entities exist in the system, the primary entity being the vehicles which enter the workshop. The vehicle inter-arrival time was obtained from the database where the WMS records the time a vehicle enters or is assigned to a bay. The inter-arrival time of takeout customers were obtained from the time a takeout invoice was produced. Using Arena's Input Analyzer, statistical distributions were fit to the data. The expressions for inter-arrival times are tabulated below.

Entity	Inter Arrival Time (Minutes)
Vehicle	**EXPO(2.77)**
Takeaway Customer	**EXPO(42.2)**

Table 4: Entity Inter-Arrival Times

Figure 10 below is depicts the data distribution for the vehicle inter-arrival time with a distribution summary from the Input Analyzer. The takeaway customer data distribution can be viewed in Appendix B.

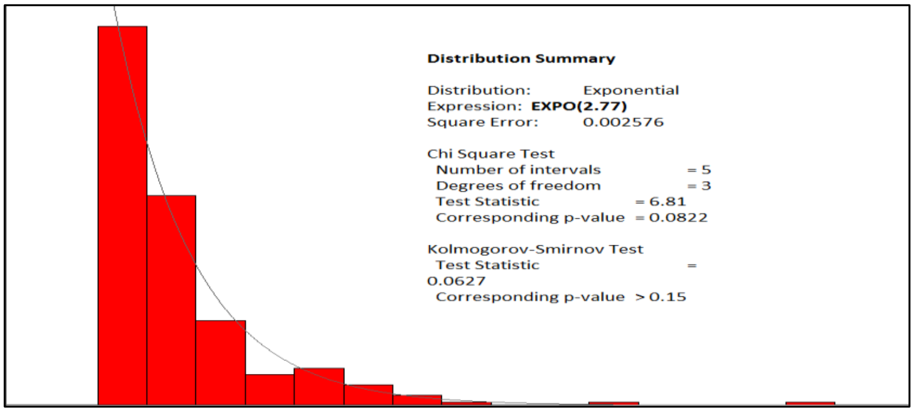


Figure 10: Vehicle Arrival Input Analyzer

4.4 Process and Delay Times

JOB ASSIGNMENT

This is modeled as a delay and the approximated time, as obtained from the interview, was allocated using an exponential distribution.

ALIGNMENT

Since the alignment process is only a single activity, the processing time was obtained using the total alignment processing time from the database and fitting a distribution to it. The quality check and rework times were estimated and fit with Uniform Distributions as it usually as a minimum and maximum value. The alignment data distribution can be viewed in Appendix B.

UNDERCARRIAGE

Since the undercarriage process is greater in complexity, simply using the total processing time is not applicable and thus the estimated individual delay times were given by the workshop manager. A shock or brake may be fitted only as a pair, and thus the estimated time for removal/fitment indicated is for a pair of parts. There is a great deal of variability in this process due to different types and sizes of parts available for different car models and lengthy delays associated with waiting for the parts to be delivered. Thus a minimum and maximum time was given for each input and a triangular distribution was used to accommodate this variability. Quality checks have a minimum and maximum time. Rework times vary for undercarriage and is thus fit with a Random Distribution.

Tyre/Wheel Services

The tyre fitment and balancing process is even more complex and simply using the total processing time from the database will not be applicable to the model. Therefore, close estimates for each individual activity and delays were obtained by the dispatch manager. The time indicated is for removal, stripping, balancing and fitting is for one tyre/wheel only. For the case where more tyres are serviced, the activity time will simply be expression given one tyre, added two, three or four times. The dispatch time is considerably less than that of the undercarriage process as tyres are available majority of the time in the warehouse which is directly linked to the dispatch. Similar to the previous two processes, an estimate for quality check is fit with a Random distribution as it mostly involves checking that bolts/nuts are not loose. The rework time usually takes between two to two and a half minutes and thus is estimated it be fit with a uniform distribution.

The table below summarizes the random distributions for the activities described above.

Category	Input Variable	Expression (Minutes)
Job Assignment	Job Assignment Delay	**EXPO(1)**
Alignment Process	Alignment Process Time	**-0.001 + EXPO(11.5)**
	Quality Control Time	**UNIF(1,2)**
	Alignment Rework Time	**UNIF(0.5,1)**
Undercarriage Process	Part Removal Brakes	**TRIA (3, 4, 8)**
	Part Removal Shocks	**TRIA(10, 20, 22)**
	Walk to Dispatch Delay	**UNIF (0.5, 1)**
	Dispatch Activity	**TRIA (2, 15, 30)**
	Dispatch Authorization	**EXPO (1)**
	Part Fitment Brakes	**TRIA (3, 4, 8)**
	Part Fitment Shocks	**TRIA(10, 20, 22)**
	Quality Control Time	**UNIF(2, 2.5)**
	Rework Time	**EXPO(10)**
Tyre Process	Tyre Removal	**TRIA (0.5, 1, 2)**
	Walk to Ops Room Delay	**UNIF (0.5, 1)**
	Tyre Stripping Time	**UNIF (1, 2)**
	Walk from Ops to Dispatch Delay	**UNIF (0.3, 0.5)**
	Dispatch Activity	**EXPO(2)**
	Dispatch Authorization	**EXPO(1)**
	Tyre Fitting Time	**TRIA(1, 2, 2,5)**
	Tyre Balancing Time	**TRIA(0.5, 1, 2)**
	Tyre Fitment	**TRIA (0.5, 1, 2)**
	Quality Check	**EXPO(3)**
	Rework Time	**UNIF(2, 2.5)**

Table 5: Process and Delay Times

4.5 INPUT PROBABILITIES

Customers opt to have one or a combination of services done. The system is modeled such that when a vehicle entity is created, attributes as to which type of service or services are given to every entity. Information as to the number of invoices processed per day as well as what service was conducted for each vehicle is available from the database. With the use of Pivot Tables in Microsoft Excel, the sum of each service type conducted was computed and divided by the number of invoices processed. In this manner, the probabilities of vehicles that do tyre fitment, balancing or undercarriage were obtained. The Microsoft Excel computations can be viewed in Appendix B.

In addition to service types for each transaction indicated in the data, the product type and quantity are also available. In this manner, the probabilities for shocks or brakes together with the probability of one or two pairs were acquired. Further from this information, the probability as to the amount of tyres: between one and four, is estimated. The probability as to what percentage of customers who require a tyre/wheel service do fitment and balancing or simply balancing only is also obtained from the data. The rework probabilities were given as an estimate from the workshop manager. Jobs pass the quality check majority of the time and thus the chance for a rework is extremely small for all services. The input probabilities are summarized in the table below.

Category	Input Variable	Probability (%)
Service Type Probability	Tyre Fitment and Balancing	**82.38**
	Undercarriage	**8.55**
	Alignment	**39.81**
Alignment	Alignment Rework	**5**
Undercarriage	Shocks Only	**71.53**
	Brakes Only	**26.64**
	Shocks and Brakes	**1.82**
	One Pair Shocks	**23.71**
	Two Pair Shocks	**76.29**
	One Pair Brakes	**98.82**
	Two Pair Brakes	**1.18**
	UC Rework Probability	**5**
Tyre	Balancing Only	**73.44**
	One Tyre/Wheel	**29.17**
	Two Tyres/Wheels	**34.90**
	Three Tyres/Wheels	**2.08**
	Rework Probability	**33.85**

Table 6: Input Probabilities

4.6 FINANCIAL DATA

The aim of the project is to maximize the throughput rate of the workshop. The profit generated is directly linked to the number of vehicles per day and thus profit may be used as a surrogate measure for the throughput rate. The relevant revenues and costs associated with the workshop was obtained from an interview with the workshop manager.

REVENUE

The revenue is expressed per job for each service type. The values are linked to the revenue earned from purely conducting the service in the workshop and thus the sales from tyres, wheels and parts are not included. For wheels/tyres, the revenue is expressed in unit cost in terms of one individual tyre (multiplied with the number of tyres, between one and four). For undercarriage, the revenue is expressed in terms of a pair of parts for either brakes or shocks (multiplied with two for two pairs). Lastly, for alignment the revenue is an average value earned from an alignment service as it differs with regards to the vehicle model.

Service Type	Description	Revenue (R/Job)
Balancing Only	One Wheel	**26**
Fitment and Balancing	One Wheel/Tyre	**50**
Shocks	One Pair	**120**
Brakes	One Pair	**85**
Alignment	Average	**160**

Table 7: Revenue Inputs

COST

Labour costs are expressed in terms of cost per 196 hours per employee. The table below summarizes the cost per employee per day. The total labour cost will be computed at the end of a simulation run and subtracted from the total revenue generated per job to determine the profit. The total cost is the sum of the unit costs multiplied by the number of each type of resource and therefore as the resource configuration varies, the total cost will change for each scenario.

Employee	Cost per month (R/196 hours)	Cost per Day (R/ 8 hour day)
Job Assigner	7000	**285.71**
Tyre Technician	5110	**208.57**
Undercarriage Technician	5750	**234,69**
Alignment Technician	6850	**279.59**
Dispatchers	4750	**193,87**
Quality Controller	10 000	**408.16**

Table 8: Resource Unit Costs

Electricity costs to run machines and bays apply only to the Fitment Machines, Balancing Machines and Alignment Bays. The tyre fitment bays and undercarriage bays do not require electricity as they use hydraulics to lift the vehicles. The electricity cost is computed per job and thus when it is modeled in Simio, the cost per job will be subtracted from the total revenue each time an entity moves through one of the machines or the alignment bay. The table below summarizes the power required per resource and the cost for each job. The rate used is R1.60 per kilowatt.

Resource	Kilowatt used per Job	Cost (R/Job)
Fitment Machine (one tyre)	3	**4.80**
Balancing Machine (one wheel)	2	**3.20**
Alignment Bay	3	**4.80**

Table 9: Resource Electricity Costs

Chapter 5: Simulation Model

5.1 As-Is Model Construction

5.1.1 High-Level Process

The As-Is model representing the workshop was constructed using the Standard Object Library in Simio. The inputs obtained from the data analysis in Chapter 4 were built into the model. The components of the high-level process of the workshop was constructed as discussed in section 3.4: Translation to Simio.

5.1.2 Low-Level Processes

The individual low-level processes for each sub process namely: Tyre Fitment/Balancing, Alignment, Undercarriage, Takeaway, Job Assignment were modeled using the add-on processes which are available is Appendix C.

The Job Assignment and Dispatch sub-processes simply involve seizing the Job Assigner and Dispatcher respectively, delaying the time to conduct the activity and thereafter releasing the worker.

The Alignment add-on process seizes the technician before processing. The Alignment processing time obtained from the data analysis is built into the Alignment server. Once the process is complete, the quality controller is seized and delayed to complete the check and then released. A decision by chance is used to determine if a rework is required, if it is not the technician is released and the job is complete. Else, a delay is added on for a rework and the quality control must conducted again.

The Tyre/Wheel fitment and balancing add on process is greater in complexity. After the technician is seized, a decide object by probability is used to determine how many tyres are required. Thereafter, another decide object is used to determine whether it is fitment and balancing or balancing only. For fitment, the fitment machine is seized and delayed. Thereafter the dispatchers and dispatch manager are seized, delayed and released. Once the fitment machine is released, the balancing machine is seized and delayed and released. Lastly, there is delay to fit the tyres back onto the vehicle. The quality check is conducted in the same manner as above. It is noted that the process time in the server is set to 0 as the total process time will be a sum of all the delays.

The Undercarriage add-on process is modeled in a similar manner to the Tyre Fitment add-on process.

5.1.3 Model Entity

Service Attribute

Once vehicle entities are created, attributes need be assigned to each vehicle as to what service or services it requires. Three states are created in the model entity: 'Do_Tyre', 'Do_UC' &'Do_Alignment'. An add-on process is created at the source object to assign these attributes to the vehicles randomly using discrete distributions. For example, if a vehicle enters 17,62% of the time the variable 'Do_Tyre' will return a value of 0, whilst the rest of the time it will have a value of 1 meaning the entity will do a tyre service approximately 83% of the time.

ROUTING LOGIC

In the case of tyres only and undercarriage only, the vehicle is routed to the sink model as the job is complete. However for service combinations, once a vehicle exits a process it must determine where to be routed to next. But first, in order to ensure a vehicle does not return to the service again, state variables are created in the model entity namely: 'Tyre_Done', 'UC_Done' and 'Alignment_Done'. Initially, these states are set to 0. When a vehicle exits a bay, an assignment is made to set the respective variable to 1. Thus, if a vehicle has all its required attributes equal to 1, it will be routed to the sink object. Else, it will be routed to the bay where the attribute is still 0 to ensure that service is completed. In this manner, the model will ensure the vehicle goes through all its required services once.

Once a vehicle is assigned with attributes, the routing logic is determined. It must first be determined what services are required, either Tyres only; Tyres & Alignment; Alignment & Undercarriage; Tyres, Undercarriage and Alignment or Alignment only. These combinations are routed to separate nodes using their state variables, for example: 'Do_Tyres' = 1 & 'Do_Alignment' = 1 & 'Do_UC' = 0 means the vehicle requires tyre and alignment services. Once it gets to the node, the vehicle must decide which service must be completed first. The rule follows whichever service bay has the shortest queue. The expression used to determine the queue length is indicated below. All the service categories are routed in this manner.

TOTAL REVENUE

A state is created in the model entity called 'TotalRevenue' which is set to 0. An assignment is made for each service type to increment the revenue by the specific values obtained from the data analysis for each service the entity is assigned to. Further assignments are made in order to decrement the revenue with regards to the electricity costs per job associated to the fitment, balancing and alignment machines. A tally is created at the sink called 'RevenueTally' to obtain the total revenue for the run.

5.1.4 Simulation Parameters

The workshop operates between 8:00 AM to 5:00 PM with a break of one hour in between. Thus the simulation run is set to eight hours to represent the workshop operations for one day.

5.2 Verification & Validation

The process of model verification entails ensuring the model performs the way it was intended to. A thorough investigation of the input parameters and model logic is required to ensure errors do not exist. Debugging is done if any errors exist in order that the simulation runs fully to completion. Further, a vehicle can be physically seen moving through the system through the use of animation. This verifies that entities are moving correctly through the system.

The validation of a simulation model includes comparing and ensuring that the model performance is a true representation of the real system performance. This is done by comparing the model outputs such as throughput rate after a simulation is run to the real life system.

The vehicle throughput rate, takeaway customer throughput rate and total revenue per day were compared to the real life values. Although the model will not be exactly the same as the real life system due to assumptions made, it was found that the model outputs are consistent and very similar to the real system data.

Further, the statistical time distributions seem to be consistent with the estimates provided by the workshop manager. In this manner the model is validated and proves to be a sufficient representation of the workshop system.

A three dimensional view of the model whilst it is running is shown in the figure below.

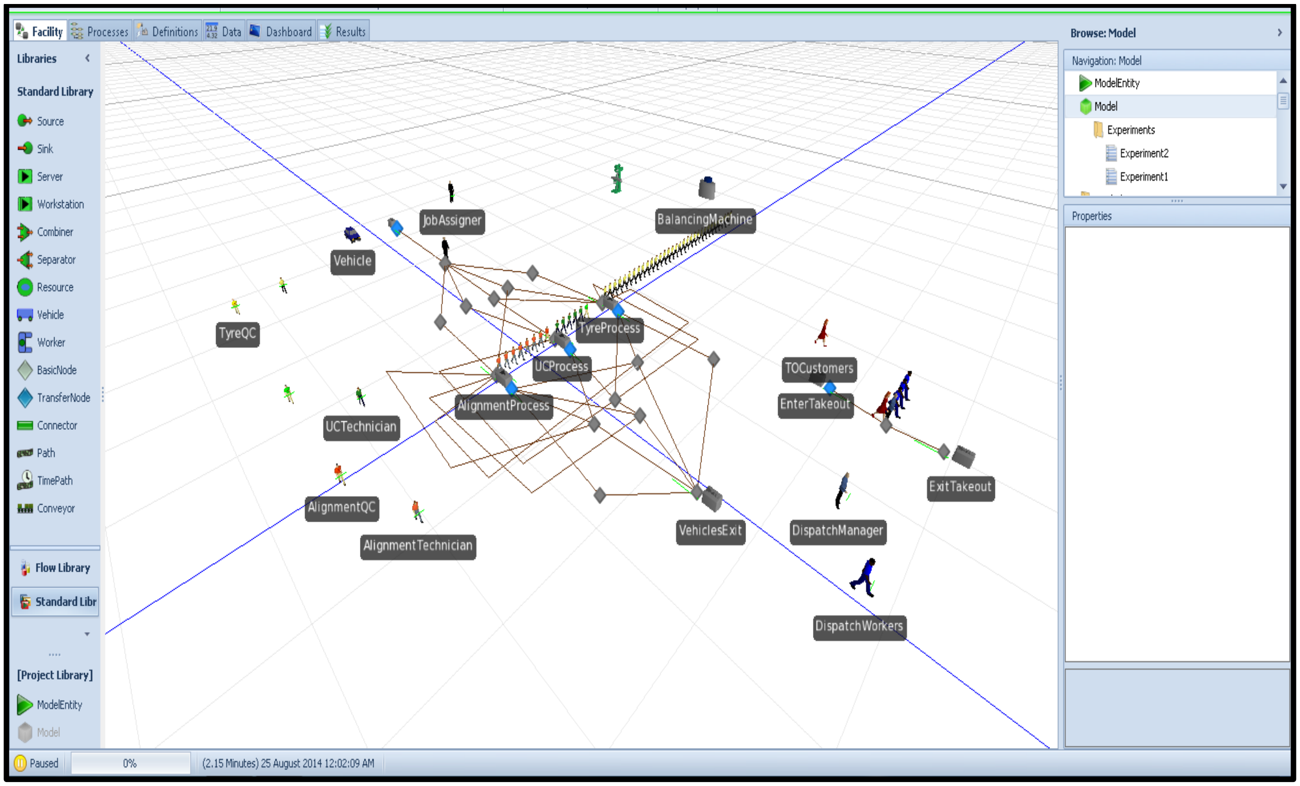


Figure 11: Three Dimensional Model Facility View

5.3 Experimental Design

The aim of the simulation study is to identify and improve capacity constrained resources and bottlenecks. An experiment includes generating various scenarios in order to test alternative resource capacities to obtain the best balance, with the aim of maximizing the throughput. However, the scenario which generates the highest throughput rate is not necessarily the best option if it incurs a high cost due to an increased number of resources. This must be considered in the experimental design.

5.3.1 OptQuest

The add-on for experimentation in Simio called OptQuest, is used. OptQuest evaluates many possible solutions to find optimal results. By describing the simulation experiment, OptQuest automatically searches for input controls to either maximize or minimize the objective.

CONTROLS

Workshop resource capacities will serve as controls to the experiment which include the capacities of service bays, technicians and quality controllers for all services. Also included in the controls are the capacities of job assigners, dispatchers, balancing and fitment machines.

RESPONSES

The main objective is to maximize the throughput rate. Since the profit is directly dependent on the number of vehicles serviced per day, profit is used as a surrogate measure of the throughput rate. Thus the objective of the experiment is to maximize the primary response, which is the profit generated per day. Profit is defined by the Total Revenue earned per day less the total cost.

The expression for **total revenue** is the sum of the revenue obtained from each job and is computed in Simio as:

RevenueTally.Average x RevenueTally.NumberOfOccurrences

The expression for **total cost** is expressed as the sum of each resource unit cost multiplied with the number of each type of resource and is computed in Simio as:

(208.57 x TyeTechnicianCapacity) + (234.69 x UCTechnicianCapacity) + (279.59 x AlignmentTechnician) + (193.87 x DispatchersCapacity) + (408.16 x TyreQCCapacity) + (408.16 x UCQCCapacity) + (408.16 x AlignmentQCCapacity) + (285.71 x JobAssignerCapacity)

OptQuest generates the possible optimal solutions in terms of alternative resource configurations. By maximizing profit, the revenue will be maximized. At the same time the total cost will be minimized and consequently the number of resources required will be reduced. In this manner, resource idle time is addressed and improved, ensuring resources are utilized more efficiently.

The resource parameters which are not included in the expression for cost which are Fitment Machine Capacity, Balancing Machine Capacity and Alignment Machine Capacity are used as responses. The objective for each one is to be minimized to ensure optimal results achieved. The resources capacities included in the cost expression will be inherently decreased in order to minimize cost.

The results from the OptQuest Experiment can be viewed in Appendix D.

Chapter 6: Simulation Results & Analysis

6.1 As-Is Results

Once the model is run to completion, Simio generates results in the form of a pivot grid and a report to summarize the outputs of the simulation run. For the purpose of this model, the most important output concerned would be the throughput rate of the vehicle entity in order to meet the objectives of this project. The results relating to the outputs of the model entities is provided below.

The results indicate the number of entities in the system, the time the entity spends in the system and the number of entities destroyed which is the throughput per day. For the vehicle entity it is shown that the throughput rate totaled a number of 165 vehicles for the simulation run. The maximum time spent in the system by an entity is just over 2 and a half hours, the minimum time is approximately 3 minutes and average of 33 minutes. This validates the model as it represents the real life situation. Lastly it indicates that the average number in the system is 11 vehicles.

Object Type	Object Name	Data Source	Category	Data Item	Statistic	Average Total
ModelEntity	TOCustomers	[Population]	Content	NumberInSystem	Average	0.1970
					Maximum	2.0000
			FlowTime	TimeInSystem	Average (Min...	8.1833
					Maximum (Mi...	21.4241
					Minimum (Min...	0.6733
			Throughput	NumberCreated	Total	13.0000
				NumberDestroyed	Total	13.0000
	Vehicle	[Population]	Content	NumberInSystem	Average	11.0176
					Maximum	23.0000
			FlowTime	TimeInSystem	Average (Min...	33.3096
					Maximum (Mi...	156.9556
					Minimum (Min...	3.0078
			Throughput	NumberCreated	Total	183.0000
				NumberDestroyed	Total	165.0000

Figure 12: As-Is Model Results

An As-Is scenario was generated to obtain the profit generated in a day for the base case model. The simulation run generated a revenue of R25 339.80 and a profit of R12 443,20 per day.

Design | Response Results | Pivot Grid | Reports

Scenario		Replications		Controls													Responses	
Name	Status	Required	Completed	Balanci...	Fitment...	JobAssig...	TyreBayC...	UCB...	Alignment...	Dispacther...	TyreTechC...	UCTec...	Alignme...	TyreQC...	UcQ...	AlignmentQCCapacity	Revenue	Profit
Scenario1	Completed	10	10 of 10	16	16	1	32	5	7	3	32	5	7	1	1	1	25339.8	13443.2

Figure 13: As-Is Experiment Results

6.2 Experimental Results & Analysis

The results from the OptQuest experiment is available in Appendix D. The scenarios which produce the best outputs is compared to the base model and analysed to provide recommendations to Malas.

6.2.1 Output Analysis

SMORE plots (Simio Measure of Risk & Error) is a graphical tool for the analysis and comparison of scenarios. It is useful in making decisions as to which scenarios are the best alternatives.

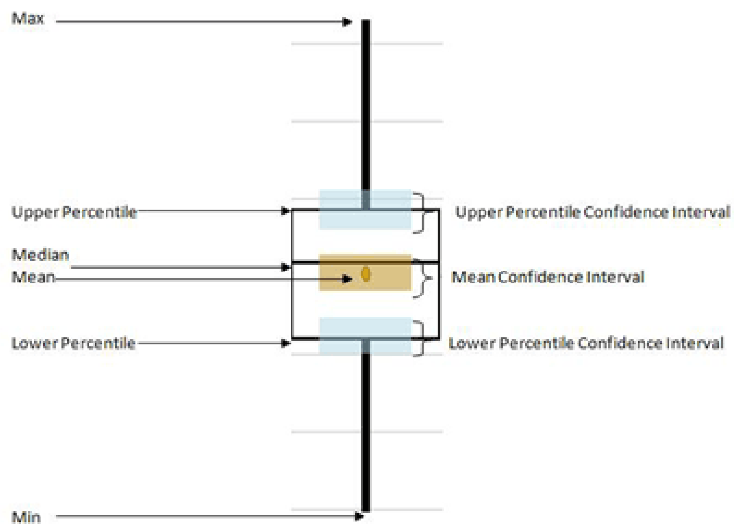


Figure 14: Simio SMORE Plot

The scenario which generates the highest profit is considered the best alternative. However, since the simulation model generates random variables, the values may change each time the model is run. Further, it is best to provide more than one recommendation to management in order to enable them to choose the most applicable solution, in line with the company's policies.

Thus, a range of the best performing alternatives must be analysed. The SMORE plots for the profit response are used to identify potential solutions. The plots provide a graphical representation of the results and thus alternatives may be compared with ease. Since the goal is to maximize profit, the alternatives which fall within the range of greater than R20 000 are considered. However, alternatives which appear within this range with low minimum values are not considered.

The plots which overlap each other, in terms of mean confidence interval, within this range are statistically significantly similar to each other and will produce similar results. Thus, they serve as potential solutions, and are compared with each other.

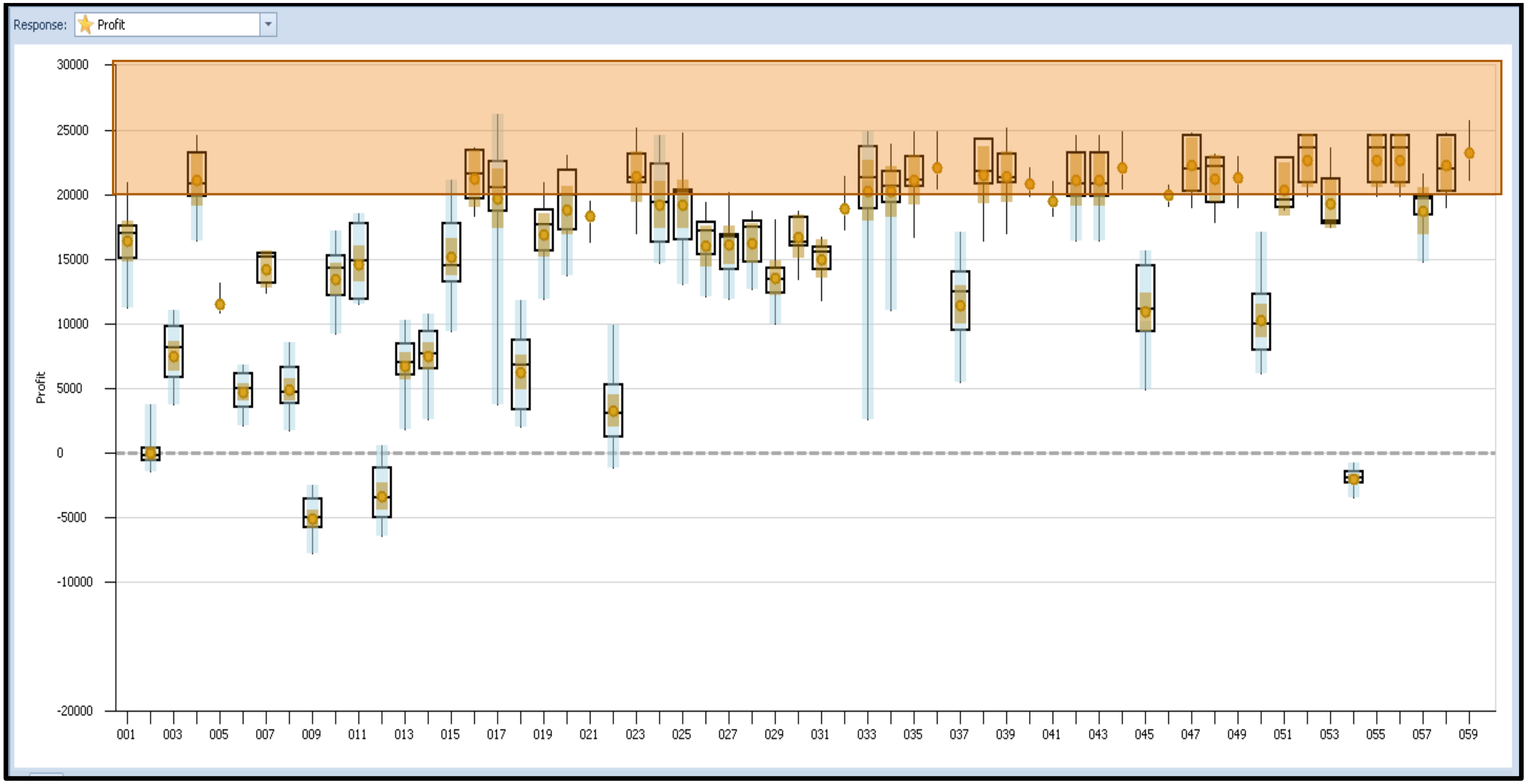


Figure 15: SMORE Plot Results

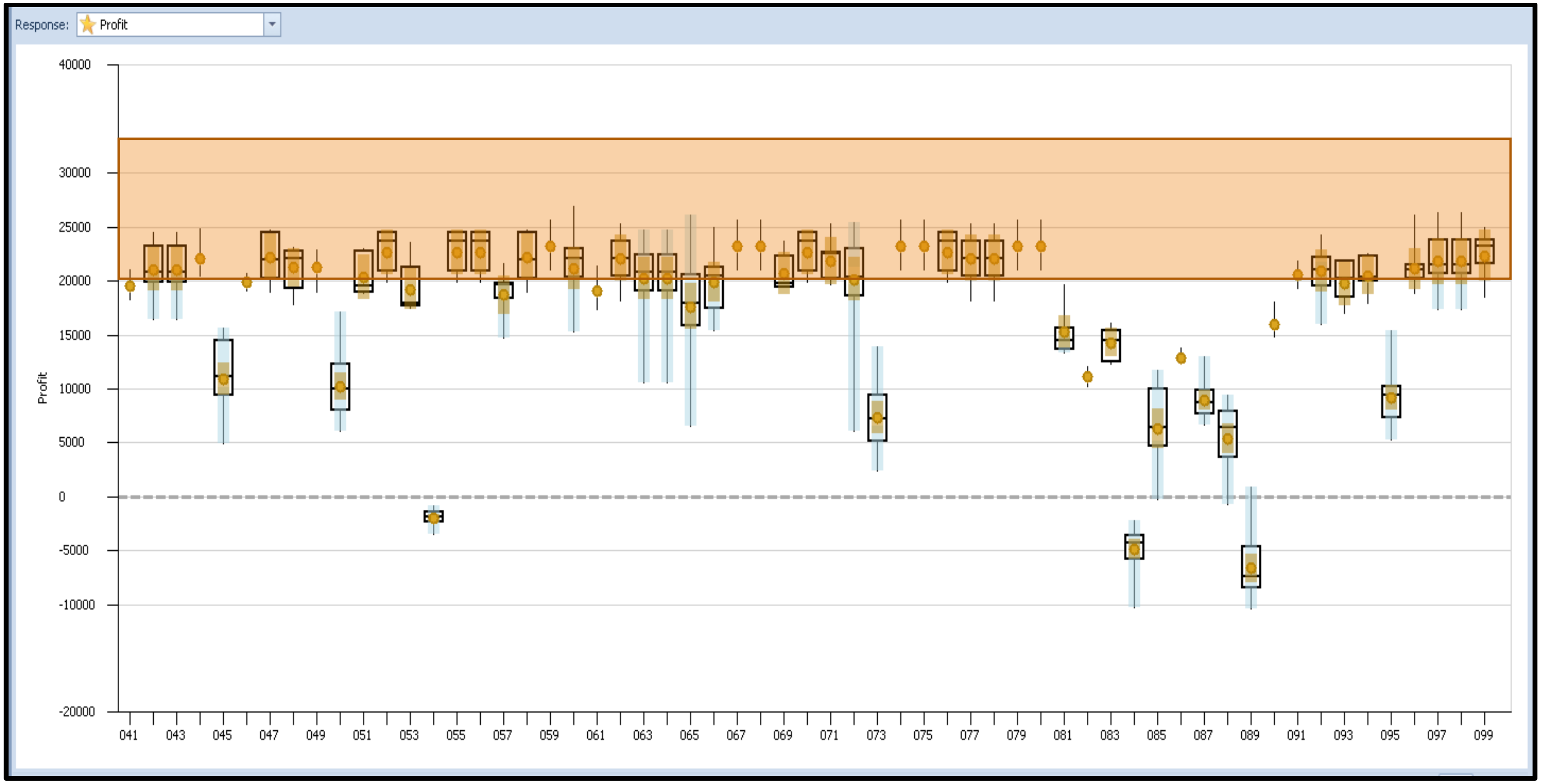


Figure 16: SMORE Plot Results 2

6.2.2 Analysis of Alternatives

As discussed above, potential solutions were selected based on the alternatives with the highest profits and those which are statistically significantly similar to them.

The 14 most feasible alternatives selected based on the SMORE plots are identified and tabulated below. Their combinations of resource configurations are included as well as their outputs generated per day, profit and throughput.

Scenario	Balancing Machine	Fitment Machine	Job Assigners	Tyre Bay	UC Bay	Alignment Bay	Dispatchers	Tyre Technician	UC Technician	Alignment Technician	Tyre QC	UC QC	AI QC	Profit (R/Day)	Throughput (Vehicles/Day)
Base Model	**16**	**16**	**1**	**32**	**5**	**7**	**3**	**32**	**5**	**7**	**1**	**1**	**1**	**13443.20**	**165**
36	2	3	2	16	1	7	2	11	1	2	2	2	2	**22127.40**	**186**
44	2	3	2	15	1	7	2	11	1	2	2	2	2	**22127.40**	**186**
52	2	4	2	16	2	7	2	11	1	3	2	2	2	**22621.80**	**190**
55	2	4	2	15	2	6	2	11	1	3	2	2	2	**22621.80**	**190**
56	2	4	2	17	2	8	2	11	1	3	2	2	2	**22621.80**	**190**
59	2	4	2	12	2	5	2	10	1	4	2	2	2	**23225.10**	**190**
67	2	4	2	12	2	6	2	10	1	4	2	2	2	**23225.10**	**190**
68	1	4	2	11	2	5	2	10	1	4	2	2	2	**23225.10**	**190**
70	2	4	2	17	2	7	2	11	1	3	2	2	2	**22621.80**	**190**
74	2	4	2	13	2	5	2	10	1	4	2	2	2	**23225.10**	**190**
75	2	4	2	13	2	6	2	10	1	4	2	2	2	**23225.10**	**190**
76	2	4	2	15	2	8	2	11	1	3	2	2	2	**22621.80**	**190**
79	2	4	2	13	2	7	2	10	1	4	2	2	2	**23225.10**	**190**
80	2	4	2	13	2	12	2	10	1	4	2	2	2	**23225.10**	**190**

Table 10: Potential Solutions

It is clear from the results that in order to improve profits, the number of resources must be decreased substantially. This is done to ensure the total cost is decreased as well as to remove resources which are under-utilized. By doing so the profits have increased significantly in comparison to the base model which generated a profit of R13 443 and a throughput rate of 165 vehicles per day. For this simulation run, the maximum profit achieved per day is R23 225 and in terms of throughput rate, 190 vehicles per day.

From the best resource configurations provided it is indicated that majority of the time, the following resources capacities will always be most optimal when there are:

- 2 balancing machines ;
- 4 fitment machines;
- 2 job assigners;
- 2 of each type of quality controller;
- 1 undercarriage technician;
- 2 undercarriage bays;

The various capacities for tyre bays, alignment bays, tyre technicians and alignment technician are illustrated in the graphs below.

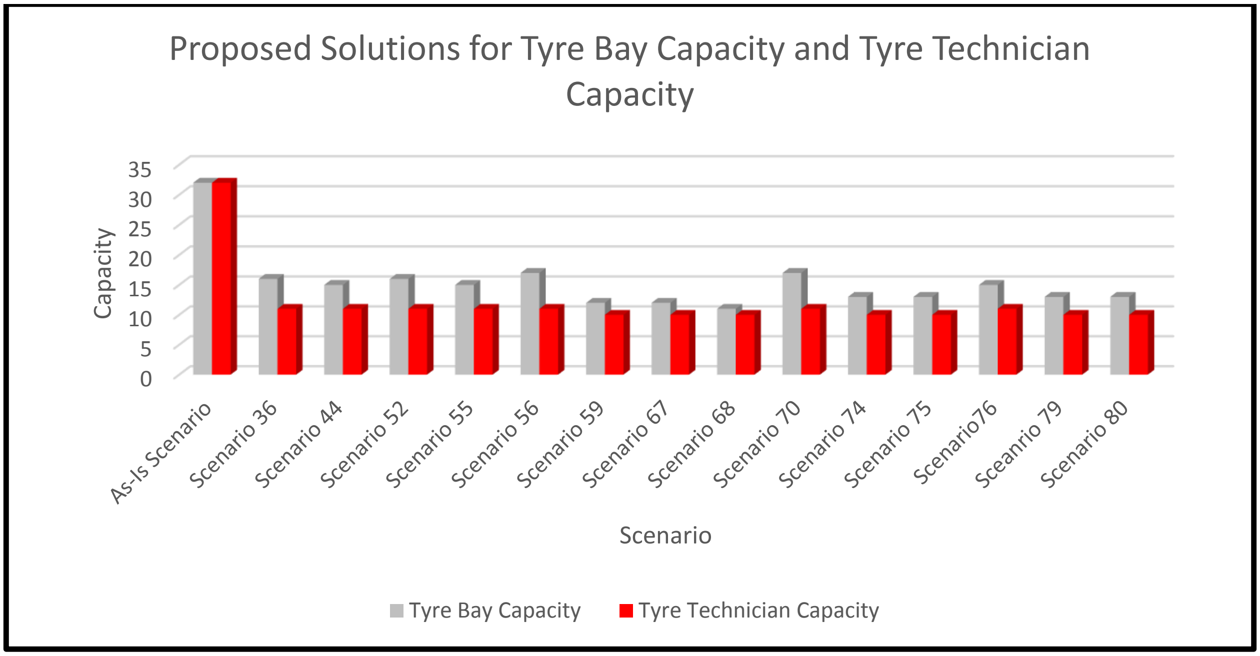


Figure 17: Tyre Bay and Technician Capacity Comparison

It is illustrated that the number of tyre bays and technicians required are much less than the current scenario. Further, it is better to have a lower number of tyre technicians than bays in order to decrease inefficiencies and improve the technician utilization. The proposed solutions for the tyre bays range between 13 and 17 bays whilst the tyre technicians are either 10 or 11.

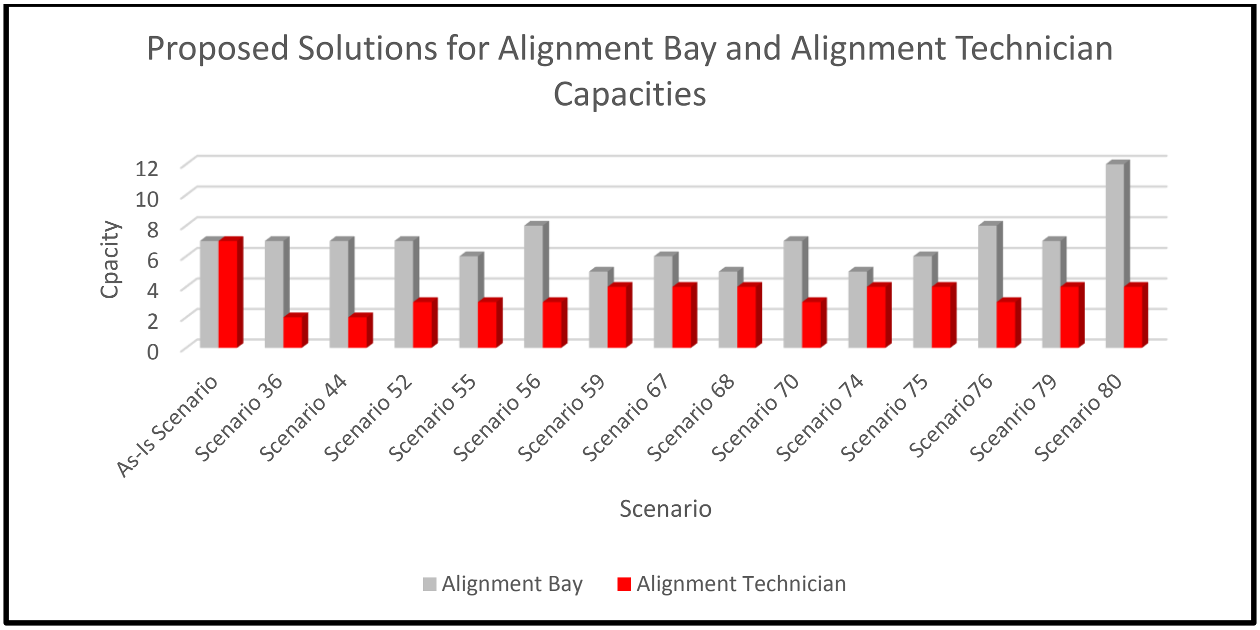


Figure 18: Alignment Bay and Technician Capacity Comparison

The graph indicates that it is more feasible in some scenarios to improve the number of alignment bays whilst others indicate it should be decreased. The proposed solutions for alignment bay capacities range between 5 and 12. It is noticed that it is better to have less technicians than bays in order to maximize utilization. The optimal configurations of alignment technicians range between 2 and 4.

However, implementation of each of these optimal solutions entails retrenching approximately half of the workforce and selling majority of the machinery, which is not a good solution for Malas. A better approach would be to retrain and deploy idle technicians to more useful areas such as job assigners and quality controllers, which are the constraints of the system. By increasing the resource capacities at these constrained areas, the system will require more technicians and machinery. Further experimentation was conducted on Simio to test for a better solution.

The following scenario produced the best result and maximised the throughput to 200 vehicles:

- 3 Job Assigners
- 3 Dispatchers
- 24 Tyre Technicians
- 5 Undercarriage Technicians
- 7 Alignment Technicians
- 17 Tyre Bays
- 3 Undercarriage Bays
- 4 Alignment Bays
- 11 Fitment Machines
- 11 Balancing Machines
- 3 Tyre Quality Controllers
- 3 Undercarriage Quality Controllers
- 3 Alignment Quality Controllers

6.3 CONCLUSION & RECOMMENDATIONS

The workshop at Malas Drivestyle Centre was found to be constrained by its operations in order to expand and deliver more. Management were concerned regarding the low throughput rate currently experienced as it hinders the company's ability to satisfy the additional demand which is expected to witness a phenomenal growth over the next couple of years.

The workshop inefficiencies resulted in long queues, low job flow completion rates and decreased machine & technician utilization. Thus, the aim of the project was to identify bottlenecks and constrained resources and improve them to ensure the throughput rate is maximized.

From the OptQuest simulation results, it is evident that by decreasing the number of resources, the throughput rate and profit is significantly increased. This indicates that a large number of resources were under-utilized.

The objective was to maximize the profit, which is a surrogate measure for throughput, feasible possible solution were developed. OptQuest developed an optimal set of solutions by maximizing the revenue whilst decreasing the number of resources required. In this manner, idle resources were removed inherently in the experiment.

From the 100 scenarios developed, all the alternatives which produced the highest profits were considered. From these, using the SMORE plot charts, the alternatives which are statistically similar were selected as they will produce similar results to each other every time the simulation is run.

The optimal resource configurations for Malas is tabulated in Table 10 above. However, implementation of these optimal solutions entails retrenching approximately half of the workforce and selling majority of the machinery. A better approach is to retrain idle technicians and deploy them to more useful areas. Further experimentation was conducted considering this and a proposed solution was made to Malas to increase the number of Job Assigner and Quality Controllers to a capacity of 3 for each type (as they are constraints of the system), keep the dispatchers capacity at the same level and reduce the various other resources to the capacities indicated above.

By re-allocating and implementing one of these solutions, the throughput and consequently the profits will be improved which meets the objective of this project. Further, resources will be used more efficiently and issues in the workshop such as long queues and waiting times will be improved leading to increased customer satisfaction.

A suggestion for future improvements and expansion to satisfy an additional demand would be to build an extra control into the model to determine how the resources should be re-allocated as the demand (inter-arrival time of entities) is increased.

To conclude, the project aims to deliver a model to the firm to act as a decision support system to aid in strategic future plans. It is highly recommended to implement this solution to ensure the strategic objectives of Malas may be achieved.

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Appendices

Appendix A: Industry Sponsorship Forms

Department of Industrial & Systems Engineering
Final Year Projects
Identification and Responsibility of Project Sponsors

All Final Year Projects are published by the University of Pretoria on *UPSpace* and thus freely available on the Internet. These publications portray the quality of education at the University and have the potential of exposing sensitive company information. It is important that both students and company representatives or sponsors are aware of such implications.

Key responsibilities of Project Sponsors:

A project sponsor is the key contact person within the company. This person should thus be able to provide the best guidance to the student on the project. The sponsor is also very likely to gain from the success of the project. The project sponsor has the following important responsibilities:

1. Confirm his/her role as project sponsor, duly authorised by the company. Multiple sponsors can be appointed, but this is not advised. The duly completed form will considered as acceptance of sponsor role.
2. Review and approve the Project Proposal, ensuring that it clearly defines the problem to be investigated by the student and that the project aim, scope, deliverables and approach is acceptable from the company's perspective.
3. Review the Final Project Report (delivered during the second semester), ensuring that information is accurate and that the solution addresses the problems and/or design requirements of the defined project.
4. Acknowledges the intended publication of the Project Report on UP Space.
5. Ensures that any sensitive, confidential information or intellectual property of the company is not disclosed in the Final Project Report.

Project Sponsor Details:

Company:	Malas Pty Ltd
Project Description:	~~De~~ Analysis of the Workshop at Malas Privestyle centre to test alternative resource configurations in order to maximise the throughput rate.
Student Name:	Firdous Tayob
Student number:	10309820
Student Signature:	S Tayob
Sponsor Name:	IMTIAZ RAHIMTOLA
Designation:	C.E.O.
E-mail:	IMTIAZ@MALAS.CO.ZA.
Tel No:	012 - 3577799
Cell No:	0828978687
Fax No:	086 647 0855
Sponsor Signature:	

APPENDIX B: ANALYSIS OF DATA

InvoiceDa	InvoiceNu	CustomerName	SalesPerso	RegistrationNuml	VehicleEx	Release	Stor	Items	Quanti	JobCodi	BayNumb	FirstN	LastName	JobType	TechStartedJo	TechFin	VehicleAssign	VehicleAss	TechCo	TotalJ	TotalBugetedTime
1/4/2014	351687	First National Bank Merchant Acquiring	RIYAZC	GFZ019G	18:17:38	10:47:42		SABA2	1	A200	A04	A-JOE	RATSHEKANI	Alignment	12:57:32	13:04:45	12:57:30	12:55:13		7	
1/4/2014	351687	First National Bank Merchan	RIYAZC	GFZ019G	18:17:38	10:47:42		GO195/55VR1	4	T005	T28	JABULAN	MAHLANGU	Tyres	12:33:41	12:41:13	11:27:10	11:08:30	11:35:01	8	
1/4/2014	352843	OTTO	LUSINDAC	LOOSE	15:09:15	12:09:15		SABB2	4	T003	T25	GIDEON	JOHANNES BR	Tyres	11:48:18	12:20:19	11:48:07	11:24:19	12:09:58	32	
1/4/2014	352843	OTTO	LUSINDAC	LOOSE	15:09:15	12:09:15		SABF1	4	T002	T25	GIDEON	JOHANNES BR	Tyres	11:48:18	12:20:19	11:48:07	11:24:19	12:09:58	32	
1/4/2014	352843	OTTO	LUSINDAC	LOOSE	15:09:15	12:09:15		MS1460WAEP	4	T009	T25	GIDEON	JOHANNES BR	Tyres	11:48:18	12:20:19	11:48:07	11:24:19	12:09:58	32	
1/4/2014	352877	CE DEWINNAAR	LUSINDAC	WJW105GP	15:27:29	13:03:57		SABA4	1	A202	A02	A-APRIL	MABOTE	Alignment	15:01:42	15:11:24	15:01:41	14:47:31		10	
1/4/2014	352877	CE DEWINNAAR	LUSINDAC	WJW105GP	15:27:29	13:03:57		CO245/40YR17	1	T006	T17	T-STEVEN	RENEKE	Tyres	13:31:33	14:06:36	13:23:35	13:05:10	14:05:34	35	
1/4/2014	352879	PJ VAN WYK	RICOE	CDH889GP	09:30:31	07:45:05		SABA2	1	A200	A02	A-APRIL	MABOTE	Alignment	09:08:07	09:29:48	09:08:06	09:02:09		21	
1/4/2014	352879	PJ VAN WYK	RICOE	CDH889GP	09:30:31	07:45:05		RE165/80TR13	4	T005	T24	GIDEON	JOHANNES BR	Tyres	07:51:30	08:57:10	07:51:17	07:39:38	07:54:09	66	
1/4/2014	352879	PJ VAN WYK	RICOE	CDH889GP	09:30:31	07:45:05		MRFR1751355	4	T009	T24	GIDEON	JOHANNES BR	Tyres	07:51:30	08:57:10	07:51:17	07:39:38	07:54:09	66	
1/4/2014	352906	SAPS - Division Training -Log	TOMSM	BRG009B	15:10:40	09:16:29		CO185/65HR14	4	T005	T20	T-BEN	SITHOLE	Tyres	09:26:39	10:03:32	09:26:37	09:11:22	09:29:56	37	
1/4/2014	352912	TB SEKGOBELA	THEMBAM	FHF812GP	08:50:50	07:45:45		SABA4	1	A202	A05	A-JOE	RATSHEKANI	Alignment	08:19:20	08:30:58	08:19:19	08:16:05		11	
1/4/2014	352912	TB SEKGOBELA	THEMBAM	FHF812GP	08:50:50	07:45:45		BA185/60HR14	2	T005	T27	MICHAEL	SITHOLE	Tyres	07:50:23	08:04:47	07:50:18	07:39:48	07:54:24	14	
1/4/2014	352913	Mr A KOBO	RICOE	HWZ531GP	15:10:44	08:03:31		SABAI	1	A208	A06	ELIAS	MOHLALA	Alignment	09:44:41	09:56:56	09:44:29	08:24:17		12	
1/4/2014	352913	Mr A KOBO	RICOE	HWZ531GP	15:10:44	08:03:31		SA175/70TR13	1	T005	T01	ANDRIES	RATHLOGO	Tyres	08:12:02	08:20:19	08:11:59	08:05:58	08:15:32	8	
1/4/2014	352917	DP COERTZEN	THEMBAM	KCC073GP	15:10:47	07:45:27		BA175/70TR13	2	T005	T06	ERIC	LEBYANE	Tyres	12:14:46	12:14:49	12:11:32	07:46:18		0	
1/4/2014	352918	MR RIKHOTSO	RICOE	FGF435N	09:33:46			SABA4	1	A202	A03	ANDRIES	MFETE	Alignment	08:30:46	09:00:03	08:30:45	08:20:41		30	
1/4/2014	352919	Messrs BEREA DRUKKERY	RICOE	NRZ375GP	09:16:10	08:10:55		SABA2	1	A200	A07	ZACHARIA	THOBANE	Alignment	08:54:45	09:06:20	08:54:44	08:54:38		12	
1/4/2014	352919	Messrs BEREA DRUKKERY	RICOE	NRZ375GP	09:16:10	08:10:55		GABG56102	2	U100	U01	UC-JOHA	SILUNA	Under Carria	08:12:59	08:39:17	08:12:57	08:12:30	08:14:11	27	
1/4/2014	352919	Messrs BEREA DRUKKERY	RICOE	NRZ375GP	09:16:10	08:10:55		GABG56171	2	U100	U01	UC-JOHA	SILUNA	Under Carria	08:12:59	08:39:17	08:12:57	08:12:30	08:14:11	27	
1/4/2014	352921	Auto Parts Distributors (Pty)	RIYAZC		09:33:57	08:41:31		DU205/40WR1	4	T006	T31	JAN	NYUNDU	Tyres	08:30:34	09:20:21	08:30:29	08:16:41	08:46:40	50	
1/4/2014	352921	Auto Parts Distributors (Pty)	RIYAZC		09:33:57	08:41:31		MRSPE1770WI	4	T010	T31	JAN	NYUNDU	Tyres	08:30:34	09:20:21	08:30:29	08:16:41	08:46:40	50	
1/4/2014	352922	LT MAOTAUNG	MUZAFFARD	XRG629GP	16:31:07	08:09:05		SABA4	1	A202	A05	A-JOE	RATSHEKANI	Alignment	16:09:19	16:21:25	16:06:46	16:02:44		12	
1/4/2014	352922	LT MAOTAUNG	MUZAFFARD	XRG629GP	16:31:07	08:09:05		MN205/40WR	2	T006	T02	T-JONA	COKA	Tyres	11:24:31	11:24:37	10:47:31	10:37:51		0	
1/4/2014	352923	M MASHISHI	RICOE	BSX872N	09:49:30	08:14:24		SABA2	1	A200	A04	GERHARD	HENNING	Alignment	08:26:54	08:37:28	08:26:52	08:16:46		11	
1/4/2014	352923	M MASHISHI	RICOE	BSX872N	09:49:30	08:14:24		BA185/60HR14	4	T005	T22	SIMON	MAPULANE	Tyres	09:04:13	09:38:43	09:04:09	08:53:03	09:16:21	34	
1/4/2014	352924	JJ JOUBERT	TOMSM	NRZ733GP	15:09:29	08:25:45		DU145/80TR10	4	T005	T31	JAN	NYUNDU	Tyres	09:20:53	09:35:21	09:20:50	08:30:22		15	
1/4/2014	352926	Messrs GOLFWAGEN	SEVENDRAS	RFK227GP	08:42:56	08:11:13		CO165/80TR13	2	T005	T18	ABEL	MAKWELA	Tyres	08:19:00	08:34:34	08:18:57	08:13:57	08:27:13	15	
1/4/2014	352929	TJ SIBEKO	RICOE	RDF190GP	09:58:29	09:07:48		SABA4	1	A202	A01	JACQUES	TREDOUX	Alignment	09:50:55	09:54:48	09:50:53	09:47:41		4	
1/4/2014	352929	TJ SIBEKO	RICOE	RDF190GP	09:58:29	09:07:48		CO175/70TR14	4	T005	T19	NAREN	SANKAR	Tyres	09:07:13	09:43:28	09:07:11	09:02:33	09:12:26	36	
1/4/2014	352930	MG MODISHA	TOMSM	PTN159GP	09:16:56	08:21:41		T14P2	1	T001	T05	ABDUL	CHANDLAY	Tyres	08:50:31	09:08:25	08:31:25	08:22:51	08:36:17	18	
1/4/2014	352930	MG MODISHA	TOMSM	PTN159GP	09:16:56	08:21:41		SABF1	1	T002	T05	ABDUL	CHANDLAY	Tyres	08:50:31	09:08:25	08:31:25	08:22:51	08:36:17	18	
												GERHAR									

Figure 19: Screenshot of Data

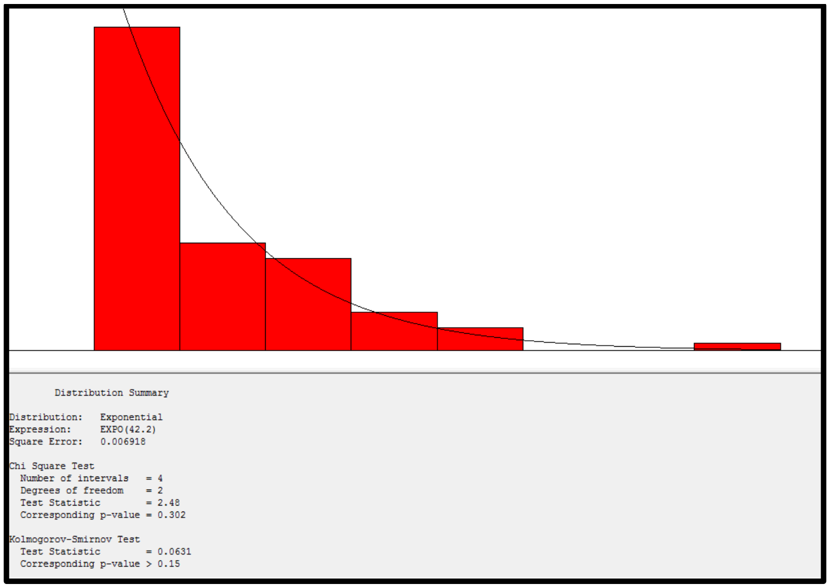

Figure 20: Takeaway Arrival Times Input Analyzer

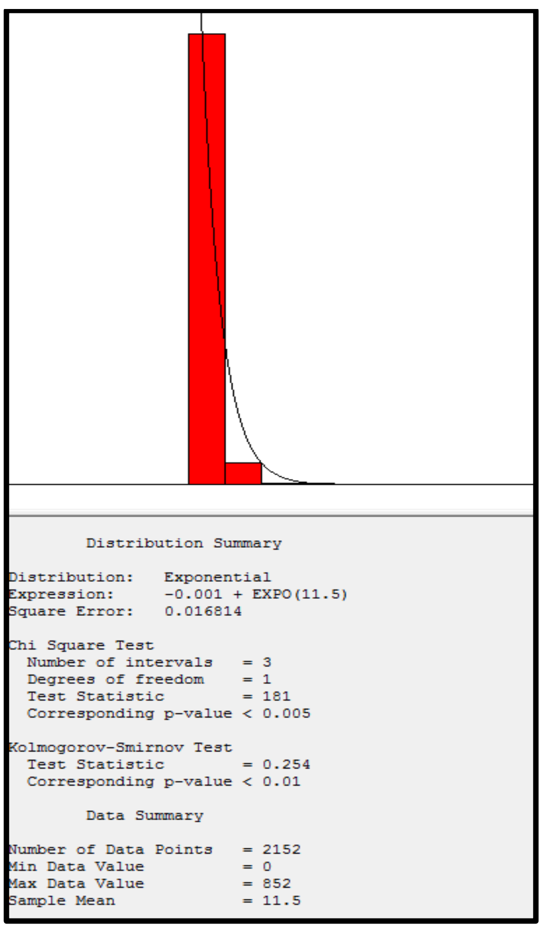

Figure 21: Alignment Process Input Analyzer

Tyres	1	0	0
⊟ 360803	0	0	0
Tyres	1	0	0
⊟ 360804	0	0	0
Tyres	1	0	0
⊟ 360805	0	0	0
Alignment	0	1	0
⊟ 360810	0	0	0
Alignment	0	1	0
⊟ 360811	0	0	0
Tyres	1	0	0
⊟ 360812	0	0	0
Tyres	1	0	0
⊟ 360816	0	0	0
Alignment	0	1	0
Tyres	1	0	0
⊟ 360818	0	0	0
Tyres	1	0	0
⊟ 360820	0	0	0
Tyres	1	0	0
⊟ 360821	0	0	0
Tyres	1	0	0
⊟ 360822	0	0	0
Tyres	1	0	0
⊟ 360823	0	0	0
Tyres	1	0	0
⊟ 360827	0	0	0
Alignment	0	1	0
⊟ 360830	0	0	0
Tyres	1	0	0
⊟ 360833	0	0	0
Tyres	1	0	0
⊟ 360834	0	0	0
Tyres	1	0	0
Grand Total	17804	8604	1848
Proportion	82.38%	39.81%	8.55%

Figure 22: Service Probabilities Computation

APPENDIX C: MODEL CONSTRUCTION

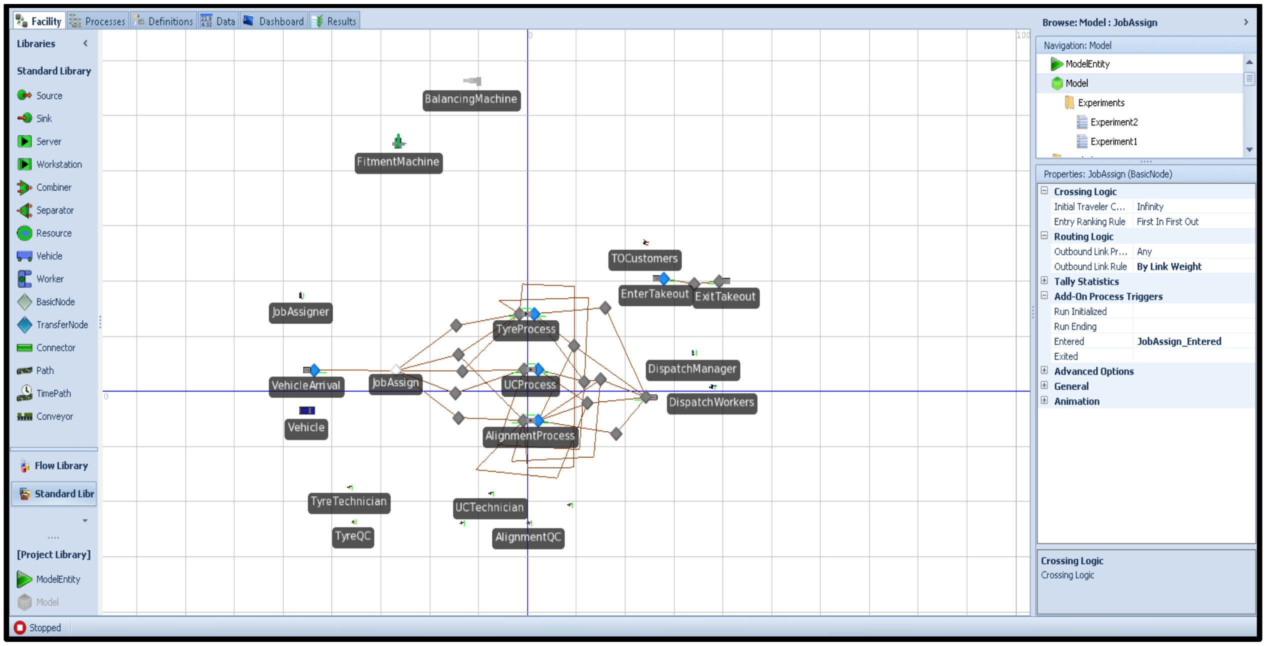

Figure 23: Model Facility View

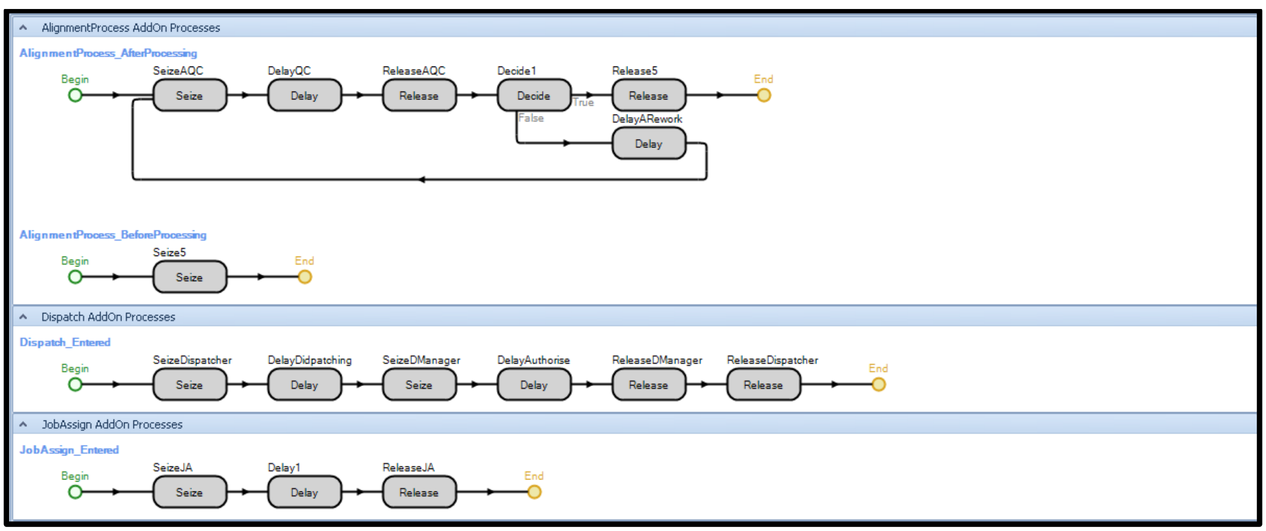

Figure 24: Alignment, Dispatch & Job Assign Add-On Processes

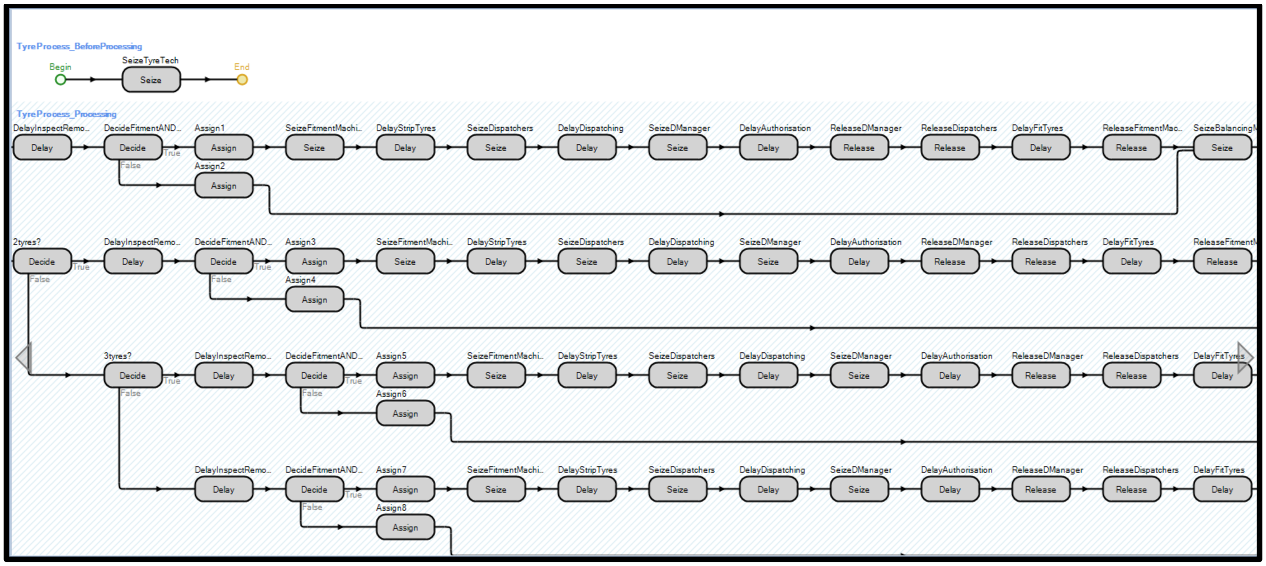

Figure 25: Tyre Fitment & Balancing Add-On Process

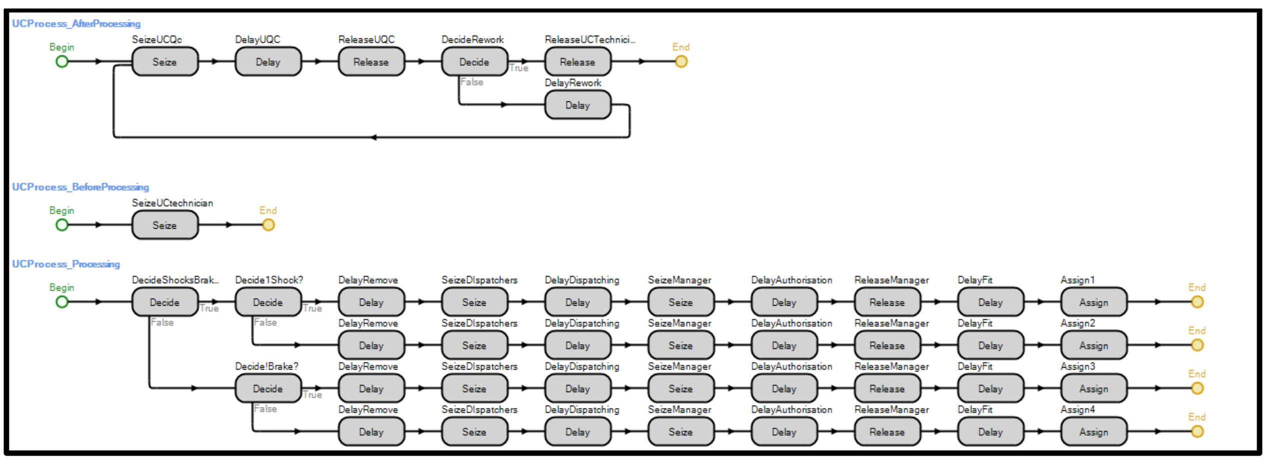

Figure 26: Undercarriage Add-On Process

APPENDIX D: OPTQUEST RESULTS

Scenario		Replications		Controls													Responses					
Name	Status	Req...	Completed	Balancin...	Fitm...	JobA...	TyreB...	UCB...	Alignment...	Dispact...	TyreTec...	UCTec...	AlignmentTe...	Tyre...	UcQcC...	AlignmentQCCapacity	**Profit**	Balancin...	Fitm...	Revenue	Throughput	AlignmentBay
001	Compl...	13	13 of 13	9	9	3	20	6	7	3	20	6	7	3	3	3	16386.9	9	9	29035.7	188.846	7
002	Compl...	20	20 of 20	1	1	1	1	1	1	1	1	1	1	1	1	1	-14.13	1	1	2412.78	17.15	1
003	Compl...	20	20 of 20	16	16	5	38	10	12	5	38	10	12	5	5	5	7516.03	16	16	29664	188.7	12
004	Compl...	9	9 of 9	5	5	2	10	3	4	2	10	3	4	2	2	2	21086.8	5	5	28403.1	180.111	4
005	Compl...	5	5 of 5	12	12	4	29	8	9	4	29	8	9	4	4	4	11557.6	12	12	28816.2	190	9
006	Compl...	20	20 of 20	15	7	5	8	1	12	4	3	7	2	5	3	5	4743.64	15	7	15081.5	99	12
007	Compl...	6	6 of 6	1	2	1	37	3	11	3	27	1	9	4	1	3	14197.1	1	2	26712.1	168	11
008	Compl...	20	20 of 20	16	2	5	33	9	1	3	28	9	7	4	1	5	4926.81	16	2	20927.9	151.55	1
009	Compl...	20	20 of 20	10	7	1	2	2	11	5	35	7	9	2	1	5	-5103.32	10	7	10876.1	69.1	11
010	Compl...	16	16 of 16	6	2	5	32	1	8	2	10	2	6	1	3	5	13464	6	2	23186.3	149.063	8
011	Compl...	16	16 of 16	2	9	3	17	3	12	5	31	5	5	1	1	1	14621.4	2	9	26709.5	171.563	12
012	Compl...	20	20 of 20	14	14	4	4	9	9	1	3	9	3	2	5	3	-3357.8	14	14	5637.2	37.9	9
013	Compl...	20	20 of 20	1	2	3	21	2	2	2	35	6	11	4	3	5	6700.49	1	2	24626.9	159.15	2
014	Compl...	20	20 of 20	10	11	4	33	8	12	2	30	9	1	1	2	1	7487.56	10	11	19299.7	135.7	12
015	Compl...	19	19 of 19	3	10	4	31	3	4	2	18	10	5	5	1	5	15163.8	3	10	28683.3	184.316	4
016	Compl...	6	6 of 6	5	6	2	10	4	4	2	11	4	5	2	2	2	21174.4	5	6	29213.5	183.5	4
017	Compl...	20	20 of 20	4	4	2	8	2	4	2	9	2	4	2	2	2	19707.2	4	4	26580.2	170.4	4
018	Compl...	20	20 of 20	3	3	2	10	1	3	1	8	2	3	1	2	2	6230.97	3	3	12013.8	77.05	3
019	Compl...	12	12 of 12	8	9	3	18	6	6	3	18	5	7	3	3	3	16877.5	8	9	28874.5	188.667	6
020	Compl...	12	12 of 12	9	9	2	10	6	4	3	10	6	7	3	3	2	18785.5	9	9	28654.8	183.25	4
021	Compl...	5	5 of 5	5	5	3	20	3	7	2	20	3	4	2	2	3	18377.8	5	5	28473.6	178.2	7
022	Compl...	20	20 of 20	2	2	1	3	1	2	1	3	1	2	1	1	1	3282.33	2	2	6405.97	43.15	2
023	Compl...	8	8 of 8	4	5	2	12	3	5	2	11	3	4	2	2	2	21370.5	4	5	28895.3	183.75	5
024	Compl...	15	15 of 15	4	5	2	14	3	4	2	18	2	6	2	2	2	19219.8	4	5	28529.1	181.4	4
025	Compl...	14	14 of 14	5	4	2	18	3	5	2	10	3	4	2	2	2	19227.7	5	4	26544	168.357	5
026	Compl...	12	12 of 12	7	9	3	20	6	7	3	22	6	7	2	3	3	16004	7	9	28661.8	184.083	7
027	Compl...	13	13 of 13	8	8	2	23	6	9	3	20	4	8	3	2	3	16086.6	8	8	27851.8	177.923	9
028	Compl...	10	10 of 10	8	6	3	24	4	7	3	17	6	7	2	3	4	16255.4	8	6	28278.6	183.1	7

Scenario		Replications		Controls													Responses					
Name	Status	Req...	Completed	Balancin...	Fitm...	JobA...	TyreB...	UCB...	Alignment...	Dispact...	TyreTec...	UCTec...	AlignmentTe...	Tyre...	UcQcC...	AlignmentQCCapacity	**Profit**	Balancin...	Fitm...	Revenue	Throughput	AlignmentBay
029	Compl...	11	11 of 11	2	6	2	18	3	12	5	31	4	6	1	1	2	13552.3	2	6	25807.7	164.545	12
030	Compl...	7	7 of 7	3	8	4	19	3	11	4	22	4	5	1	2	1	16726.7	3	8	27202.9	175.571	11
031	Compl...	7	7 of 7	3	2	3	35	3	10	3	22	1	9	4	1	4	15018.3	3	2	27470	180.429	10
032	Compl...	5	5 of 5	5	5	3	23	3	8	3	20	3	6	2	2	3	18890.6	5	5	29739.4	189.6	8
033	Compl...	20	20 of 20	4	4	2	13	3	5	2	11	3	4	2	2	2	20291.1	4	4	27815.9	178	5
034	Compl...	13	13 of 13	5	6	2	10	4	4	2	11	3	5	2	2	2	20214.4	5	6	28018.8	177.231	4
035	Compl...	8	8 of 8	4	5	2	12	3	5	2	11	4	4	2	2	2	21135.8	4	5	28895.3	183.75	5
036	Compl...	5	5 of 5	2	3	2	16	1	7	2	11	1	2	2	2	2	22127.4	2	3	28623.6	186.6	7
037	Compl...	20	20 of 20	1	3	2	15	1	8	2	12	1	1	2	2	2	11476.7	1	3	17901.9	124.75	8
038	Compl...	8	8 of 8	4	5	2	12	3	5	2	10	3	4	2	2	2	21510.3	4	5	28826.5	183.25	5
039	Compl...	8	8 of 8	4	5	2	13	3	5	2	11	3	4	2	2	2	21370.5	4	5	28895.3	183.75	5
040	Compl...	5	5 of 5	5	5	2	9	4	4	2	11	4	5	2	2	2	20878.4	5	5	28917.5	179.8	4
041	Compl...	5	5 of 5	5	6	2	12	4	4	2	11	4	5	2	2	2	19512.9	5	6	27552	181.2	4
042	Compl...	9	9 of 9	5	5	2	13	3	4	2	10	3	4	2	2	2	21086.8	5	5	28403.1	180.111	4
043	Compl...	9	9 of 9	5	5	2	12	3	4	2	10	3	4	2	2	2	21086.8	5	5	28403.1	180.111	4
044	Compl...	5	5 of 5	2	3	2	15	1	7	2	11	1	2	2	2	2	22127.4	2	3	28623.6	186.6	7
045	Compl...	20	20 of 20	2	2	2	16	1	8	2	11	1	1	2	2	2	10945.3	2	2	17161.9	117.65	8
046	Compl...	5	5 of 5	1	3	2	17	1	7	2	11	1	2	2	2	2	19933.6	1	3	26429.8	173.6	7
047	Compl...	7	7 of 7	4	5	2	12	3	5	2	10	2	4	2	2	2	22253.1	4	5	29334.6	183.143	5
048	Compl...	7	7 of 7	2	5	2	16	3	5	2	10	1	4	2	2	2	21234.4	2	5	28081.2	181.571	5
049	Compl...	5	5 of 5	4	3	2	12	1	7	2	11	3	2	2	2	2	21294.1	4	3	28259.7	184.8	7
050	Compl...	20	20 of 20	1	2	2	18	1	8	2	12	1	1	2	2	2	10252.3	1	2	16677.6	114.15	8
051	Compl...	6	6 of 6	3	3	2	16	1	7	2	11	1	2	2	2	2	20378.4	3	3	26874.7	174.667	7
052	Compl...	6	6 of 6	2	4	2	16	2	7	2	11	1	3	2	2	2	22621.8	2	4	29397.6	190	7
053	Compl...	8	8 of 8	3	4	2	15	1	6	2	11	1	2	2	2	2	19251.9	3	4	25748.2	169	6
054	Compl...	20	20 of 20	1	16	1	38	10	1	5	1	1	1	5	5	1	-2000.37	1	16	4467.3	33.45	1
055	Compl...	6	6 of 6	2	4	2	15	2	6	2	11	1	3	2	2	2	22621.8	2	4	29397.6	190	6
056	Compl...	6	6 of 6	2	4	2	17	2	8	2	11	1	3	2	2	2	22621.8	2	4	29397.6	190	8

Scenario			Replications		Controls													Responses					
	Name	Status	Req…	Completed	Balancin…	Fitm…	JobA…	TyreB…	UCB…	Alignment…	Dispact…	TyreTec…	UCTec…	AlignmentTe…	Tyre…	UcQcC…	AlignmentQCCapacity	**Profit**	Balancin…	Fitm…	Revenue	Throughput	AlignmentBay
☑	057	Compl…	9	9 of 9	1	4	2	18	2	8	2	11	1	2	2	2	2	18705.9	1	4	25202.1	172.333	8
☑	058	Compl…	7	7 of 7	4	5	2	13	3	5	2	10	2	4	2	2	2	22253.1	4	5	29334.6	183.143	5
☑	059	Compl…	5	5 of 5	2	4	2	12	2	5	2	10	1	4	2	2	2	23225.1	2	4	30072	190.2	5
☑	060	Compl…	12	12 of 12	4	5	2	16	3	7	2	11	2	3	2	2	2	21192.7	4	5	28203.3	177.417	7
☑	061	Compl…	5	5 of 5	1	4	2	18	2	8	2	12	1	3	2	2	2	19075.4	1	4	26059.8	166.2	8
☑	062	Compl…	7	7 of 7	3	4	2	16	2	7	2	11	1	3	2	2	2	22110.6	3	4	28886.5	188.286	7
☑	063	Compl…	17	17 of 17	4	5	2	13	3	5	2	10	2	3	2	2	2	20285.3	4	5	27087.3	173.765	5
☑	064	Compl…	17	17 of 17	4	5	2	13	2	6	2	10	2	3	2	2	2	20285.3	4	5	27087.3	173.765	6
☑	065	Compl…	20	20 of 20	3	3	2	14	2	7	2	11	2	2	2	2	2	17645.8	3	3	24376.8	156.15	7
☑	066	Compl…	12	12 of 12	3	4	2	14	2	6	2	11	2	3	2	2	2	19882.2	3	4	26892.7	173.5	6
☑	067	Compl…	5	5 of 5	2	4	2	12	2	6	2	10	1	4	2	2	2	23225.1	2	4	30072	190.2	6
☑	068	Compl…	5	5 of 5	2	4	2	11	2	5	2	10	1	4	2	2	2	23225.1	2	4	30072	190.2	5
☑	069	Compl…	6	6 of 6	2	4	2	9	2	4	2	10	1	4	2	2	2	20725.3	2	4	27572.2	184.167	4
☑	070	Compl…	6	6 of 6	2	4	2	17	2	7	2	11	1	3	2	2	2	22621.8	2	4	29397.6	190	7
☑	071	Compl…	6	6 of 6	2	4	2	12	2	5	2	11	1	4	2	2	2	21834.8	2	4	28890.2	186.5	5
☑	072	Compl…	19	19 of 19	2	4	2	17	2	8	2	10	1	3	2	2	2	20173.3	2	4	26740.5	171.368	8
☑	073	Compl…	20	20 of 20	2	4	2	5	2	1	2	9	1	5	2	2	2	7372.7	2	4	14290.6	96.6	1
☑	074	Compl…	5	5 of 5	2	4	2	13	2	5	2	10	1	4	2	2	2	23225.1	2	4	30072	190.2	5
☑	075	Compl…	5	5 of 5	2	4	2	13	2	6	2	10	1	4	2	2	2	23225.1	2	4	30072	190.2	6
☑	076	Compl…	6	6 of 6	2	4	2	15	2	8	2	11	1	3	2	2	2	22621.8	2	4	29397.6	190	8
☑	077	Compl…	7	7 of 7	3	4	2	14	2	6	2	11	1	3	2	2	2	22110.6	3	4	28886.5	188.286	6
☑	078	Compl…	7	7 of 7	3	4	2	15	2	6	2	11	1	3	2	2	2	22110.6	3	4	28886.5	188.286	6
☑	079	Compl…	5	5 of 5	2	4	2	13	2	7	2	10	1	4	2	2	2	23225.1	2	4	30072	190.2	7
☑	080	Compl…	5	5 of 5	2	4	2	13	2	12	2	10	1	4	2	2	2	23225.1	2	4	30072	190.2	12
☑	081	Compl…	11	11 of 11	15	15	4	13	9	2	4	10	7	8	4	5	3	15277.5	15	15	28058.9	177	2
☑	082	Compl…	5	5 of 5	10	14	2	31	6	4	1	34	8	4	1	1	5	11189.4	10	14	24899.1	162.6	4
☑	083	Compl…	7	7 of 7	4	14	1	31	7	12	3	35	8	3	4	5	3	14284.3	4	14	30065.8	190.571	12
☑	084	Compl…	20	20 of 20	12	2	4	2	1	3	5	31	10	6	2	5	1	-4874.9	12	2	10992.7	71.85	3

Scenario			Replications		Controls													Responses					
	Name	Status	Req…	Completed	Balancin…	Fitm…	JobA…	TyreB…	UCB…	Alignment…	Dispact…	TyreTec…	UCTec…	AlignmentTe…	Tyre…	UcQcC…	AlignmentQCCapacity	**Profit**	Balancin…	Fitm…	Revenue	Throughput	AlignmentBay
☑	074	Compl…	5	5 of 5	2	4	2	13	2	5	2	10	1	4	2	2	2	23225.1	2	4	30072	190.2	5
☑	075	Compl…	5	5 of 5	2	4	2	13	2	6	2	10	1	4	2	2	2	23225.1	2	4	30072	190.2	6
☑	076	Compl…	6	6 of 6	2	4	2	15	2	8	2	11	1	3	2	2	2	22621.8	2	4	29397.6	190	8
☑	077	Compl…	7	7 of 7	3	4	2	14	2	6	2	11	1	3	2	2	2	22110.6	3	4	28886.5	188.286	6
☑	078	Compl…	7	7 of 7	3	4	2	15	2	6	2	11	1	3	2	2	2	22110.6	3	4	28886.5	188.286	6
☑	079	Compl…	5	5 of 5	2	4	2	13	2	7	2	10	1	4	2	2	2	23225.1	2	4	30072	190.2	7
☑	080	Compl…	5	5 of 5	2	4	2	13	2	12	2	10	1	4	2	2	2	23225.1	2	4	30072	190.2	12
☑	081	Compl…	11	11 of 11	15	15	4	13	9	2	4	10	7	8	4	5	3	15277.5	15	15	28058.9	177	2
☑	082	Compl…	5	5 of 5	10	14	2	31	6	4	1	34	8	4	1	1	5	11189.4	10	14	24899.1	162.6	4
☑	083	Compl…	7	7 of 7	4	14	1	31	7	12	3	35	8	3	4	5	3	14284.3	4	14	30065.8	190.571	12
☑	084	Compl…	20	20 of 20	12	2	4	2	1	3	5	31	10	6	2	5	1	-4874.9	12	2	10992.7	71.85	3
☑	085	Compl…	20	20 of 20	14	2	4	27	6	11	2	8	8	10	1	4	4	6333.83	14	2	17879.8	114.6	11
☑	086	Compl…	5	5 of 5	1	7	5	34	6	5	5	21	6	5	5	2	4	12872.6	1	7	26946.3	172	5
☑	087	Compl…	16	16 of 16	11	16	5	31	2	8	4	38	6	10	1	3	2	8979.9	11	16	25762.6	161.563	8
☑	088	Compl…	20	20 of 20	6	15	5	3	5	12	4	7	2	2	3	1	5	5407.36	6	15	13773.4	89.4	12
☑	089	Compl…	20	20 of 20	11	1	2	7	7	2	1	29	10	5	4	3	3	-6601.38	11	1	8038.89	51.8	2
☑	090	Compl…	5	5 of 5	10	8	2	33	2	3	2	11	3	10	5	4	4	15977.2	10	8	28036.6	182	3
☑	091	Compl…	5	5 of 5	3	6	3	13	4	11	3	10	1	4	2	2	2	20594.8	3	6	27921.2	175	11
☑	092	Compl…	9	9 of 9	4	6	2	13	3	5	3	10	1	5	3	2	2	20927.8	4	6	28656.2	184.444	5
☑	093	Compl…	6	6 of 6	6	6	3	13	5	5	3	10	2	5	3	2	2	19736.5	6	6	27985.4	186.667	5
☑	094	Compl…	6	6 of 6	7	9	3	15	3	4	3	11	2	4	3	2	2	20511.4	7	9	28689.3	183.167	4
☑	095	Compl…	20	20 of 20	16	16	5	38	1	12	1	38	10	12	5	1	1	9186.97	16	16	27294.2	176.5	12
☑	096	Compl…	8	8 of 8	5	6	2	13	3	7	2	10	2	5	2	3	2	21123	5	6	28892.4	183.25	7
☑	097	Compl…	9	9 of 9	3	4	2	13	2	11	2	10	1	4	2	2	2	21824.1	3	4	28670.9	184.444	11
☑	098	Compl…	9	9 of 9	3	4	2	13	2	7	2	10	1	4	2	2	2	21824.1	3	4	28670.9	184.444	7
☑	099	Compl…	6	6 of 6	3	5	2	14	2	6	2	11	1	3	2	2	2	22361.2	3	5	29137	186.833	6
☑	100	Compl…	9	9 of 9	3	4	2	13	2	8	2	10	1	4	2	2	2	21824.1	3	4	28670.9	184.444	8