THE UNIVERSITY OF THE WEST INDIES
Faculty of Engineering
The Department of Mechanical and Manufacturing Engineering

MENG 6600: Mechanical MSc Research Project

TITLE: EVALUATION OF CAPACITY AND PERFORMANCE OF MAINTENANCE OPERATIONS USING A DISCRETE-EVENT SIMULATION AT THE PUBLIC TRANSPORT SERVICE CORPORATION (PTSC)

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SEPTEMBER 2022

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1. Introduction

1.1 Background to the Study

The growing use of mechanization and automation in industrial production over the past few decades has resulted in an abrupt drop in the number of production employees while simultaneously pushing up the price of production equipment. Consequently, more capital and manpower resources have been committed to the maintenance function. It is relatively unusual for certain categories of companies' maintenance and operations departments to employ up to 30% of the total workforce. Furthermore, the resources spent on maintenance tasks frequently account for most of the operational budget (DEKKER, 1996). As a result, the most difficult challenge for maintenance managers is determining whether cash resources and labour resources are being used effectively and efficiently. In an ever-changing, dynamic environment, service providers and production systems are growing more complex, and they must compete at both the national and international levels. Many decisions are often made on a consistent basis in a range of settings. The majority of these decisions are based on the manager's past expertise or on basic approximations. It may be financially advantageous in certain cases because of the time-sensitive nature of the problem and the restricted availability of resources.

Any infrastructure or operational modifications, on the other hand, may need careful consideration to minimize expressive losses because of growing complexity and cost. According to H. Adji et al. (2012), many industrial companies and service providers must restructure, modernize, and analyze the capability of their maintenance systems to remain competitive. Because of the growing expectations for asset availability, each of these tasks is not only challenging but also time-consuming (ALABDULKARIM; BALL; TIWARI, 2013). As a result, it is critical to use decision support tools like computer simulation and optimization to accurately estimate the behaviour of a real system as well as analyze the impact of several alternative scenarios on the system's performance. From a strictly practical approach, computer simulation allows the design and evolution of a numerical model of an existing or future system with the purpose of better understanding the system under the influence of a specific set of conditions (KELTON; SADOWSKI; SWETS, 2007). The adoption of decision support technologies, such as simulation and optimization, in the bus service business is still fairly limited at this moment. Maintenance efforts in this sector are critical to the overall functioning of the company and have a direct influence on how customers judge the value of the product.

Routine maintenance procedures may become challenging due to the huge number and variety of mechanical and electrical components contained in each vehicle, depending on the total size of the fleet. Furthermore, numerous diverse techniques of maintenance must be considered, including corrective, preventive, and predictive maintenance. After the cost of running the vehicles, Bladikas and Papadimitriou (1986) discovered that the cost of maintenance was the second largest category of operational expenditures. This expenditure accounts for around 21% of total operating expenses in a typical transportation system (PURDY; WIEGMANN, 1987). Bus service providers are constantly under pressure to improve service quality while operating costs rise and financial subsidies dwindle (HAGHANI & SHAFAHI, 2002). For the reasons stated above, bus transportation services consider maintenance operations to be one of their most significant and crucial components. It is necessary to investigate, evaluate, and assess the facility's capacity to determine the appropriate equipment, the best operating policy, and other such things to handle the challenges stated above.

In most cases, scenario testing with multiple features under a range of settings is required to determine whether the monetary expenditure will result in significant performance advantages. In the Arena simulation software, a model for the maintenance operations performed at the Public Transport Service Corporation Engineering Department Trinidad and Tobago was created as part of this inquiry. Any modifications to the physical structures, such as the number of cleaning machines, inspection pits, and cleaning areas, may need considerable study due to the amount of money required to implement these changes. As a result, the impact must be investigated so that management can make better decisions. This circumstance has created the potential for simulation.

1.2 Aim

- To evaluation the capacity and performance of maintenance operations using a discrete-event simulation at the Public Transport Service Corporation (PTSC)

1.3 Objectives

The goal of this thesis is to look at how different resource allocations at PTSC maintenance department affect its performance metrics.

The following are the specific goals of this investigation:

a. Understand the complexity of maintenance operations at PTSC;
b. Use Arena to model the main maintenance processes that occur within the Maintenance Department;
c. Determine the capacity of the processes under study;
d. Determine the average lead-time (total time) of a bus within the garage department;
e. Test alternative scenarios with a larger number of mechanical pits.

1.4 Problem Statement

Maintenance operations in the bus service sector contribute significantly to overall company profitability and have an immediate impact on how customers perceive the value of the products and services they get. Because of the variety of vehicle components, performing maintenance procedures may quickly become a complicated and time-consuming task. As a result, it is essential to undertake research of the workplace maintenance procedures and the influence of these performance metrics. The investigation aims to identify answers to the problem, and it anticipates that a variety of steps will be necessary.

1.5 Scope and Limitations

This thesis will only cover operation maintenance issues related to the use of discrete-event simulation in the process of developing and evaluating a maintenance operation. It will focus on the modelling, simulation, and visualization of vehicle flows throughout the maintenance operation.

Furthermore, the width is restricted to a specific capacity. Additionally, given that simulation capacity grows in line with the dynamics and complexity of operations, it is reasonable to expect that complicated process systems for maintenance are utilized.

Nonetheless, although these circumstances may be especially relevant to some sectors, such as the automobile and aerospace industries, complexity and dynamics are not confined to these areas. As a result, the main ideas behind this thesis are not limited to any one part of the economy, if the above conditions are met.

Regardless of the limitations outlined above, it is important to highlight that developing or just sketching a strategy that integrates all aspects and stages of the construction of a maintenance process is a difficult effort. To get a meaningful and relevant conclusion, it is necessary to combine the findings of several different study domains. To do so, many academic and industrial workers would need to work together over a lengthy period. This was obviously not possible for several reasons.

This thesis, on the other hand, is an operational research. Despite this, one of the key goals of this thesis is to establish a framework for a holistic view of one of these technologies, notably the challenges connected to the integration of discrete-event simulation into the capacity and performance of maintenance operations. This is one of the thesis's most crucial goals, as well as one of its primary aims.

2. Literature Review

This section provides a bibliographic overview of the most major academic disciplines related to this investigation. There are three subsections in this section: linked domain modelling and optimization; maintenance management; and operational research. Each component is given its own section. Operations investigation is divided into six subsections. First, the origins of operational research are addressed, as well as the historical backdrop of queuing theory and models. Second, examples of feedback control systems are offered to help the reader grasp the nature of the system under consideration. This talk finishes with a description of simulation systems and how they work. In the fourth part of this section, the simulation models are organized. The fifth stage looks at discrete event simulation. In the last part, we look at the benefits and drawbacks of employing simulation methodologies. The second section examines the maintenance function's issues and the objectives that must be met for the function to be successful. The concluding part presents a literature assessment on the use of simulation and optimization techniques in related domains.

2.1 Operations Investigation

"Operational research," as the name indicates, encompasses a wide spectrum of "operations research." This field of research is concerned with using mathematical tools to analyse and resolve problems arising from internal business operations. Manufacturing, healthcare, telecommunications, financial planning, logistics, military forces, and building and construction are just a few of the numerous public and private industries that have utilized Operations research since the content of organizations is frequently immaterial (HILLIER; LIEBERMAN, 2010). It is often regarded as a branch of applied mathematics.

Operations research (OR) may be traced back many decades to the earliest institutions that aimed to answer management issues scientifically. According to Hillier and Lieberman (2010), the phrase "operational research" is often associated with the British military during

WWII, even though scientific methodologies were utilized by organizations far earlier. Even though scientific approaches have been used in business for decades, this has happened.

Scientists were tasked by the military administration with addressing strategic and tactical difficulties. This decision was taken due to the pressing requirement to cater to many troops with limited resources. Scientists who worked with OR during the war went on to develop a variety of mathematical models to solve a variety of civilian challenges. The fast rise of the industrial sector after the war provided the impetus for this change. Organizational challenges were becoming more complicated, necessitating the use of creative approaches. According to Hillier and Lieberman (2010), two key factors in the fast rise of operational research were the quick development of OR methodology and the extensive use of computers in industry. Because of the combined effect of these two elements, the field of operational research grew rapidly.

There is no one approach to dealing with the myriad mathematical challenges that arise in the real world in operational research. Frequently, the complexity and kind of model under consideration dictate the strategy used to find a suitable solution (TAHA, 2007). It is only sometimes obvious whether a particular mathematical strategy used to improve a system is an OR technique. According to Taha, the most extensively utilized operational research approaches nowadays include linear programming, integer programming, dynamic programming, network programming, nonlinear programming, simulation models, and queuing models (2007).

Several OR approaches have the property that not all solutions are conveniently accessible in closed forms. Algorithms, which are collections of well-defined computational rules, identify these answers by repeatedly applying them to a problem until the best solution is found. The best solutions to an issue may be identified using algorithms (TAHA, 2007). Due to the complexity of the examined system, a perfect solution is often impossible; hence, it is critical to investigate a solution that comes as close to being optimum as possible.

It is often more intriguing to investigate multiple conditions and their performance metrics than to seek a single, definitive solution to an issue via scientific research. In this case, it is vital to investigate queues and find system performance measures. So, systems simulation is the best operational research method that fits the modern world.

2.2 Querying Theories and Models

"Queuing theory," according to Hillier and Lieberman (2010), is the study of all types of waiting. It generally uses queuing models to represent various queuing systems that may occur in the real world. Formulae are used in this model to explain how the real system should perform, including the average waiting time that will occur under certain scenarios.

Queue models are computer algorithms that evaluate the efficiency with which people wait in lines. These models, unlike the other optimization or reduction techniques discussed in the preceding section, do not provide an optimal or near-optimal solution; rather, they define performance measures of the waiting lines, such as the average time spent in the queue, the average time spent waiting for service, the capacity of the service facility, and the utilization rate of these facilities (TAHA, 2007).

2.3 System Modelling and Simulations

When most people consider simulation, they refer to replicating a real-world system on a temporal scale. A computer and associated software are commonly used to imitate the behaviour of a real-world process or system. It is often used to research and forecast the performance of complex systems. The simulation modelling paradigm tests the system with a predefined set of goals, such as system design enhancement, cost-benefit analysis, design parameter sensitivity analysis, etc. According to Altiok and Melamed (2007), the simulation modelling paradigm was formed. In certain circumstances, a model may be necessary to represent a simple system accurately. An acceptable solution to the problem may be based on mathematical approaches such as differential calculus, probability theory, algebraic parameters, or other techniques.

On the other hand, many real-world scenarios include systems that are so sophisticated and intricate that their mathematical models are unsolvable. A simulation of the system's behaviour over time may be valuable in various scenarios. It is impossible to get the same information from the simulation as would be obtained if the real system were examined. The data gathered via simulation is then utilized to create performance measures.

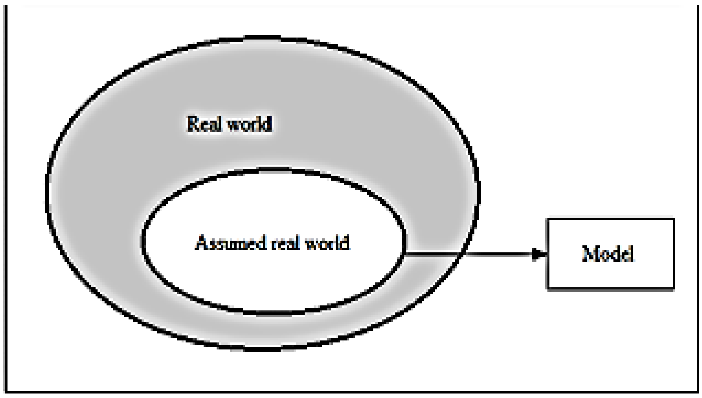
There are many constraints associated with simulation use. Creating simulation models is usually time-consuming and resource-intensive (TAHA, 2007). (TAHA, 2007). Furthermore, even on a powerful CPU, the execution time may be lengthy if the model being used is massive; this depends on the model's size. Because of these limits, it is critical to represent the important aspects of the examined system and discover the linkages between those elements. Figure 1 demonstrates the many degrees of abstraction that may be attained while creating a model. Examine the degree of generality.

According to Altiok and Melamed (2007), models are often employed to avoid the undesirable decision of constructing a real and expensive system, particularly considering the economic motives for simulation models. To address these constraints, Altiok and Melamed (2007) called for the investigation of the three motivational strands listed below prior to the development of a model:

a. Because normal operations in today's world cannot be disrupted, it may be necessary to develop a model to assess system performance in both normal and exceptional conditions. It is feasible to avoid the potentially disastrous consequences of shutting down the main system by using alternative scenario testing.

b. Predicting experimental system design success to when the system to be investigated does not yet exist, simulation is one option to consider. Building and running a physical model may be a significantly riskier and more expensive alternative to software-based system behaviour investigation.

c. Ranking and analysis of the following designs' trade-offs: It allows for a thorough examination of a variety of investment options. Requests for an e-system are often given to the bidder whose performance metrics cost the most.



Source: Adapted from Taha (2007)

Figure 1: Model development degrees of abstraction

2.4 Numerous Types of Simulations

Adapted from Kelton, Sadowsky, and This piece was written by Taha (2007) Sweats (2009) claims that there are numerous methods to categorize simulation models; nonetheless, there is a practical approach to divide them along the three dimensions given below:

a) The Distinction Between Static and Dynamic

Time is not as important in static models as it is in dynamic ones. Most of the engineering and management systems are feedback control systems that operate in a dynamic manner.

b) Is Continuous Better Than Discrete?

In continuous models, the overall state of the system is thought to change in a series of steps throughout time. A continuous system is an example of filling a tank. Changes to the system's state, on the other hand, will occur only at certain points during a discrete event. An assembly line is an example of a discrete system in which components enter and exit at predetermined intervals. In certain cases, both discrete and continuous-discrete models may be used to identify systems. In certain cases, this is correct.

c) Deterministic Versus Stochastic Characteristics

These structures are known as "mixed systems. There is no such thing as random input in deterministic models; rather, these models have fixed input timings. Examples of such techniques are procedures that strictly adhere to appointment books. Stochastic models, on the other hand, need at least some of their inputs to be random to function. Several unanticipated factors often alter the pattern of bus arrivals at a terminal. It is critical to emphasize that model inputs may be either deterministic or random since both are possible.

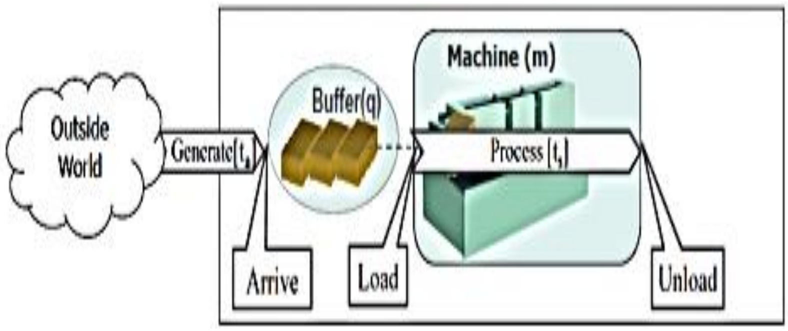
2.5 Simulation Using Discrete Events

Banks et al. (2005) used the term "discrete-event simulation" to describe computer system models in which the value of a state variable changes only at a few discrete points in time. Because real-world systems include a large quantity of dynamic data, this kind of simulation model is often analysed using numerical approaches rather than analytical methods. This is due to the complexity of real-world systems. Analytical procedures depend on mathematical inductive and deductive reasoning to arrive at a realistic solution to a problem.

Numerical approaches, on the other hand, include solving mathematical problems utilizing a range of computer equipment. Choi and Kang (2013) use the example of a single service system in a factory, which consists of a machine and a buffer, to demonstrate discrete-event simulation. The following is a description of the system's basic architecture:

a) When an entity enters the system, interaction begins in the buffer. The arrival times are defined as t a, and the entity is processed if the machine is idle. If the machine is not idle, the entity waits for it to be prepared.
b) With a service time of t seconds, the entity is processed and emptied.
c) When an entity exits the system, if the buffer is not empty, the next entity is loaded.

This system's state variables are the number of units presently stored in the buffer (represented by q) and the system's current status (represented by m), which might be idle or busy. Arrival, loading, and unloading are the three events that occur. In figure 2, he explains the general structure of the single service system, which is as follows:



Source: Choi and Kang (2013)

Figure 2: Single Service System

2.6 The Benefits and Drawbacks of Computer Simulation and Modelling

According to Banks et al. (2005), one of the key reasons why simulation is so appealing to consumers is its capacity to imitate what occurs in a real system or what is projected for a system while it is still in the design process. The information presented by the simulation model must have a one-to-one link with how the actual system works. Because of these advantages, simulation is often a viable method for addressing complicated technical and administrative problems. Simulation models, on the other hand, do not provide a single static ideal solution or a near-perfect answer.

This is distinct from optimization models. To make inferences, observations of the system's behaviour under a specified set of situations are employed. Furthermore, it may generate numerous scenarios depending on the various inputs provided, making it ideal for planning changes, deploying new solutions, or even testing a non-list hypothesis. There are nine benefits to using a simulation: existing method or practice in 1995, Pegden, Shannon, and Sadowsky published the following:

a) An examination of new operational procedures, decision rules, regulations, information flows, and timeframes.
b) Evaluate alternative hardware designs, physical layouts, transportation systems, and logistic chains without relying on the acquisition of physical infrastructure.
c) It is possible to confirm the existence of specific events and assess their feasibility.
d) To gain a better understanding of the system under study, you can either shorten or lengthen each simulation session.
e) An examination of the variables' interrelationships
f) Determine if a particular variable is important or irrelevant to the overall operation of the system.
g) Recognizing bottlenecks and describing their impact on system performance.
h) Simulation-based research may be valuable for understanding how the system really works, as opposed to how people perceive it to work.
i) Is it possible to get answers to "What if?" questions? It is especially advantageous for newly built systems.

The following are some potential drawbacks:

a) In most cases, specialized knowledge is required for the design of model structures. If two models are built by two competent people, they will most likely have certain qualities but will not be identical. Because of the unpredictability of the simulation's outputs, the results of certain simulation runs may be difficult to comprehend at times.
b) It may be difficult to discern between a system's interrelationships and randomness;
c) Simulation modelling and evaluating could take a lot of time and cost a lot of money;
d) Analytical methods, for the most part, are less costly and take less time to complete.

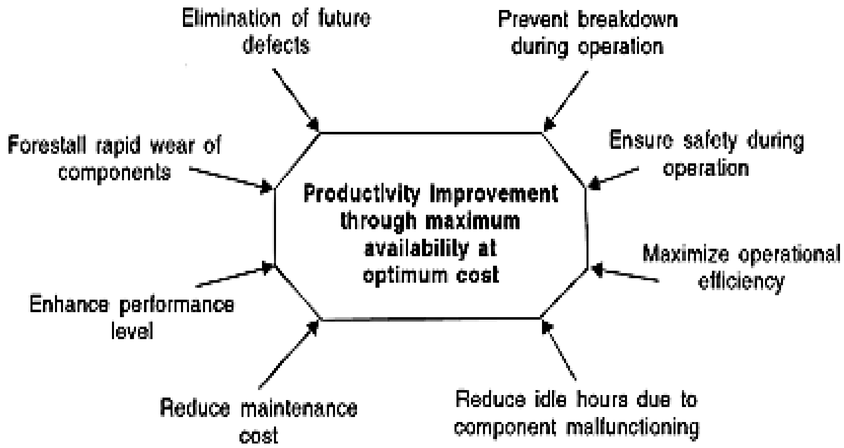
2.7 Engineering and Management of Maintenance

Because of the growing prevalence of automated manufacturing processes, maintenance has become one of the most important duties for every company. Companies and service providers must confront a growing number of new hurdles to make their goods and services available to consumers. Mishra and Pathak (2012) list a few of the challenges that maintenance departments confront.

Among these challenges are the rapid advancement of technology, which results in the rapid obsolescence of current technology; the need to keep both obsolete and modern machines operational; the need to train and upgrade the skills of maintenance personnel; the development of maintenance schedules; and the overhaul of inspection programs. The maintenance engineering role's goal is to ensure that as much of the organization's equipment and facilities as possible are available for use to encourage the attainment of the organization's goals.

Another critical part of maintenance operations is the provision of safe working conditions for both operating and maintenance personnel. Figure 3 depicts Mishra and Pathak's (2012) model, which includes a wide range of maintenance objectives.

It is critical to depend on decision support systems to efficiently handle potential difficulties and ensure that maintenance choices are made in accordance with the organization's goals. These systems might be shown, for example, using the OR methods described in the preceding sections. Optimization and simulation have been used to assist maintenance managers in their decision-making in a range of sectors, including industry and service providers. The story takes place in the 22nd century CE. The next part will give a literature review on the use of OR methods in infrastructure maintenance. Figure 3 depicts the link between preventative maintenance goals and This work was written by Mishra and Pathak (2012)



Source: Mishar and Pathak (2012)

Figure 3: Maintenance of interaction objectives

2.8 Application of Simulation and Optimization Approaches in Adjacent Fields

Optimization models may be used for maintenance tasks in a variety of ways. It was necessary to create several algorithms and simulation models to extend the life of equipment, avoid failure, schedule maintenance, and so on. According to the findings of a study done by Dekker (1996), the mathematical field of operational research has experienced remarkable advancement in maintenance optimization. Despite this, there currently needs to be more relevant research on bus depot maintenance operations simulation. Following that, it is critical to cite research on related themes.

Haghani and Shafahi (2002) previously addressed the subject of ed optimization in bus repair systems. As part of their study, they organized a variety of bus transit maintenance procedures using mathematical programming. Inputs to the model included a predefined daily operation schedule for all buses allocated to a depot and the resources available for their repair. We got solutions that were very close to optimum while maintaining reasonable calculation times. The problem of parking autos at bus terminals while accounting for random arrival times was investigated by Hamdouni, Soumis, and Desaulniers (2007). The goal was to create a system allowing many buses to park in the same area while decreasing the time spent relocating automobiles between arrivals and departures. According to Leung and Lai (2003), a sequential strategy was utilized to determine the most effective maintenance practices for a Hong Kong bus service operator. This was done via the use of a sequential strategy. The study aimed to identify when preventative maintenance on a motor vehicle engine is necessary and when it is suitable to replace an in-service motor vehicle engine.

The study's findings show that sequential approaches have many benefits over the nonhomogeneous Poisson process model, including the capacity to solve maintenance and replacement issues. Constantin and Florian (1995) proposed a nonlinear bi-programming strategy for increasing frequency in large-scale public transportation networks. The results of their approach to constructing short-term transportation networks were promising. Savchenko and Milov (2016) developed an intelligent maintenance decision support tool based on a contextual multiarmed bandit algo planning system rhythm. This solved two key issues in maintenance systems: identifying potentially dangerous situations and categorizing these instances to prescribe the best repair solution. It was decided to develop a new technique based on Bayesian categorization that would provide correct findings. The simulation of maintenance systems has received much attention in published papers.

Abdulkarim, Ball, and Tiwara give a complete market literature review (2013). In this paper, the authors propose an application of maintenance simulation models. Iwata and Mavris (2013) provide a discrete-event simulation modelling framework to enhance aerospace vehicle maintenance and logistics. Fang and Zhaodong (2014), who studied the impact of component failure rate and preventive maintenance costs on the longevity of aviation equipment, also made major contributions. This research was also quite important. In 2001, Duffuaa, BenDaya, and Andijani developed a theoretical maintenance service simulation tool.

The conceptual model has seven elements

1. **Input**
2. **Maintenance load**
3. **Planning and Scheduling**
4. **Material and Replacement Parts Supply**
5. **Equipment Availability**
6. **Quality Control**
7. **Performance Indicators**

By defining, building, and evaluating the use of simulations to quickly simulate field maintenance systems, Alabdulkarim, Ball, and Tiwari (2011) tried to bridge a research gap. In second research, Alabdulkarim, Ball, and Tiwari (2015) used a simulation-based strategy to assess asset monitoring levels for maintenance operations in second research. Their goal was to determine how cost-effectively these levels might be implemented. To investigate how the maintenance operation system handles varied degrees of asset monitoring, generic and simulation modules were created.

Duffuaa and Raouf (1992) developed a simulation model to determine how many people should work on a soft drink manufacturing facility's maintenance staff. In order to get a better understanding of the engine repair facility's production capabilities, Gatland, Yang, and Buxton (1997) developed a simulation model to investigate the impacts of facility loading on turn time, throughput, and capacity. Their model could investigate a wide range of scenarios, including engine mix, repair levels, insourcing kinds, insourcing levels, and extra non-work. In recent years, there has been a substantial growth in the adoption of a combined simulation and engine optimization approach.

Oyarbide Zubillaga, Goti, and Sanchez (2008) used a combination of discrete-event simulation and evolutionary algorithms to discover the best preventive maintenance frequency for multi-equipment systems while accounting for cost and profit restrictions. Several variables, including production, work-in-process material, quality, and maintenance, were investigated for interdependence. Roux et al. (2008) concentrated on developing a simulation and optimization platform for examining the performance of maintenance methods for industrial systems with decreasing operational characteristics as well as unexpected lifetime and repair duration. This was done to get a better understanding of how maintenance regulations affect industrial system performance. Alrabghi and Tiwari devised a paradigm in their 2016 research that would give enough information to aid both academics and practitioners in improving maintenance systems. The technique addressed contemporary issues like complexity, the optimization of several objectives, and unpredictability. In another study, Alrabghi and Tiwari (2015) evaluated the use of simulation-optimization approaches in previously published research. They determined that most of this field's research has concentrated on preventative maintenance.

3. Methodology

3.1 Introduction

The primary motivation behind this section is to introduce the supposition of reasoning that upholds this review and to present the exact examination and methodology strategies utilized. Alongside a case study, a quantitative analysis is presented as an example in the current research. Simulation software that replicates the operation of an actual bus garage. In this part, the processes used to develop the simulation model are described in depth. The Arena simulation software is offered first. Second, we begin to examine the creation and implementation of simulations. The procedure includes defining the problem, collecting pertinent data, developing the model, simulating the model's performance, assessing the findings, and providing suggestions. The third section provides an explanation of the problem as well as its definition. Finally, the technique for data collection is described. This strategy serves as the basis for the bus garage's everyday operations. As the fifth point, conditions for performing the simulation are presented. The last step is to look at the validation processes, which include choosing KPIs and comparing simulation results to real data.

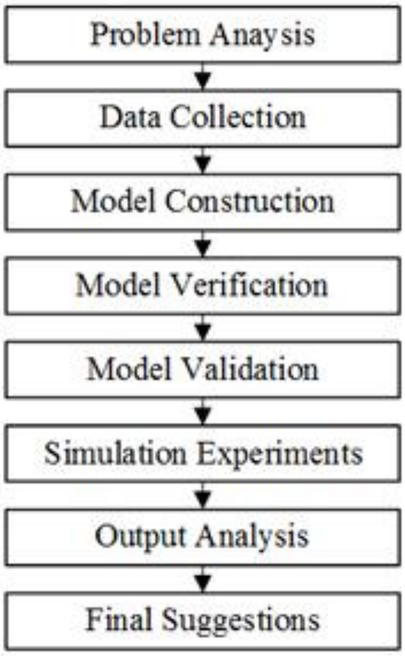
3.2 Arena Simulation

The bus depot's routines were replicated using Arena simulation software. Using this widely used discrete-event simulation application, you may model complicated systems using flowcharts and modules. Rockwell Automation develops and sells software applications. According to Kelton, Sadowsky, and Sweats (2007), Arena combines the accessibility of high-level simulators with the flexibility of simulation languages and general-purpose procedural languages such as C and C++ and the Microsoft Visual Basic® programming environment. It provides a library of graphical simulation modelling and analysis modules in various pre-made templates that may be used to create various simulation models. The Blocks and Elements panel allows immediate access to low-level modules, giving the user complete control over the simulation language. Parts of the model may be written in procedural languages for more specific situations, such as implementing complex decision algorithms or retrieving data from an external application. All these functionalities are displayed in a standard graphical user interface regardless of the organizational level. Rockwell Automation (Rockwell) creates and disseminates software. According to Kelton, Sadowsky, and Sweats (2007), Arena combines the usability of high-level simulators with the flexibility of simulation languages and general-purpose procedural languages, such as Microsoft Visual Basic® or C/C++. It does this by offering diverse, interchangeable graphical simulation modelling and analysis module templates that may be used to create a vast array of simulation models. Importing low-level modules from the Blocks and Elements panel and having access to simulation language flexibility is always feasible. For more complicated circumstances, such as complicated decision algorithms or obtaining data from an external program, it is also feasible to develop model components in the previously described procedural languages.

3.3 Methods for the Design and Execution of Simulations

Each author has a unique definition of the phases that include the design and execution of a simulation project, from inception to completion, but there are some commonalities. This research was done according to Altiok and Melamed's recommendations (2007). The proposed model is consistent with the objectives of this study.

The chosen steps are indicated in **Figure 4** below.



Source: Altiok and Melamed (2007)

Figure 4: Iterative Scheme

Figure 4 shows the eight most important parts of the Altiok and Mel simulation modelling methods, which are explained in more detail below.

a) **An Investigation of the Issue:** The first step is to determine the nature of the problem. At this point, crucial information about the situation is gathered. This includes identifying input parameters, performance and capacity measurements of interest, the process flow and regulations, system components, and the relationship between parameters and variables. Following the gathering of pertinent system operating data, an appropriate manner of representation is chosen. This may entail the use of logic flow diagrams, hierarchical trees, or any other useful technique. There may be a solution available at this time.

b) **Data Collection:** To provide an accurate description of the system's behaviour, it is necessary to gather data for estimating the model's input parameters. Real data from historical databases may be utilized to develop assumptions about the random variable distributions in a model. In the absence of data, parameter ranges must be determined by interviewing people in charge of the examined process. This step is needed to validate the model because the statistics from the system output must be compared to their counterparts in the model.

c) **Model Building**: After doing a problem analysis, collecting data, and gaining an understanding of the system's behaviour, it is essential to build a model using the collected data. It may be a general-purpose language (such as Visual Basic, FORTRAN, or C++) or a specific application that interacts with a simulation language environment (e.g. ARENA, FLEXSIM, PROMODEL, ANYLOGIC, GPSS). As noted earlier, ARENA is employed in this study.

d) **Model Validation**: Examining the final output to check that the model is accurate Model requirements must be compared to the model code. In a nutshell, the verification procedure enables the analyst to verify whether the model is running correctly and in accordance with its specifications. If differences are found, the model must be updated by changing either its code or its specification.

e) **The Model's Validation:** When it is time to validate the model, the outputs of the model are compared to the real system's behaviour. Each model must undergo validation before being deployed. Examining the model's congruence with empirical data is the way of establishing its validity (measurements of the real-life system to be modelled). If there are significant differences, the suggested model must be revaluated, necessitating adjustments. In many instances, enough model creation, verification, and validation cycles are necessary to achieve a successful model.

f) **Simulation Experiments:** The simulation trials are produced once the model's accuracy has been verified. After that, an estimate may be created to help in selecting a solution to the problem. To have a deeper understanding of how the system responds to a variety of scenarios, it is often necessary to conduct many case studies. For scenario-related performance indicators to be statistically valid, each scenario must be repeated, and its results must be averaged to get rid of any differences.

g) **Performance Measures:** The performance measures are then examined statistically and assessed rationally. During this step, several possible designs are thought about until the best one is chosen.

h) **Suggestions:** Lastly, here are some suggestions that the analyst may make closing remarks and recommendations on the underlying problem after determining which alternative is superior among many alternatives under consideration. Typically, an individual will submit a report.

3.4 Problem Description

Despite the corporation's scale, there is a shortage of reliable data about the average amount of time that buses spend waiting in the garage (also known as the lead-time) and the corporation's resource capacity. These performance indicators have never been evaluated using mathematical modelling and statistical analysis. The maintenance technical team is now updating the maintenance software as part of the implementation of a new information system. This is being done so that more data can be employed to predict the behaviour of the system. Nevertheless, it is crucial to determine if capacity constraints affect the average lead time of buses. As the garage coordinator often allocates smaller-capacity vehicles to pits during periods of heavy demand, resource allocation is also crucial. The chapter on model design describes the corporation's resources in detail. In other words, the goal of the simulation model we're discussing is to give a genuine quantitative analysis by considering the stochastic nature of garage operations and recreating those processes in order to facilitate decision-making by providing alternative scenarios. In these situations, a higher number of resources, their reallocation, and their impact on lead time and utilization are evaluated.

3.5 Data Collection

A database query will be sent to the organization's computerized maintenance program's database to collect the information required to construct the model. One of the primary reasons for the advantages associated with its utilization is the ease with which this data can be gathered, which is often achieved via automation. As a result, a substantial amount of information may be collected in a short amount of time and at a minimal cost. The maintenance records include, for instance, the date and time the bus arrived and departed, the identification number of the inspection pit, the time each vehicle was inspected, the kind of maintenance service performed, and the name of the person in charge of the service.

However, getting reliable data from the organization's automation system would take much work. On occasion, it will not be easy to get precise information on bus arrival times. The organization has no control over the specific arrival time of the buses at the terminal. As a result, the results may need to be more accurate. It is essential to evaluate manually completed forms to get more accurate data. Because of the nature of this data, massive sample sizes are not practical; consequently, only the most important findings will be included in this analysis. Arrival times are timed and recorded. In other instances, automated information and manually filled-out forms will only be available to provide a procedure duration estimate. In this case, a timer would be used to track the duration of each step manually. This covers lubrication, fuelling, external cleaning procedures, and machine-washing durations. It would estimate how long each of these processes will take. To get reliable findings, sample sizes must exceed 300 individuals.

In other instances, none of the possibilities were applicable. Only interviews with the individuals in charge of those tasks would be conducted to create an accurate time estimate for the various processes. Due to the complexity of the maintenance services, which included electrical, refrigeration, bodywork, and upholstery, the staff's expertise was utilized to assess the example's maintenance service durations. Due to the significant time investment necessary, physically collecting sample timings from various sources would be an unpleasant and laborious task. The corporation's automation system offered no information on the above processes.

After collecting the data, the information would be analyzed using the statistical program. The data will be plotted on a boxplot chart, and any outliers will be eliminated. This approach would be followed for each activity inside the simulation model's bounds. After analyzing the data, several probability distributions will be used to illustrate it. The Input Analyzer of Arena selected these distributions based on the results of a fit-all test. The value distribution with the smallest squared error will be chosen. They will be only discarded if the Kolmogorov Smirnov (K S) test result is below the acceptable threshold of 0.05.

3.6 The Arrangement of the Simulation Run

The purpose of the simulation experiment is to evaluate system performance by estimating performance metrics in many different scenario configurations. The goal of the experiment is to determine the performance of the system. When a model consists of a lot of independent probabilistic events, the observed outcomes are very sensitive to variance. In other words, the model's sequence of random numbers, often known as inputs, will provide a variety of results.

The average outcomes of each simulation iteration were utilized to evaluate performance indicators for the purposes of this investigation. A total of 30 replications, each lasting 24 hours, were determined to be necessary. The terminal is accessible 24 hours a day, seven days a week. Consequently, the processes do not cease from one day to the next; rather, they continue as if they were a part of a continuous system. This necessitated the prioritization of the construction of a warm-up time.

3.7 Model Verification and Validation

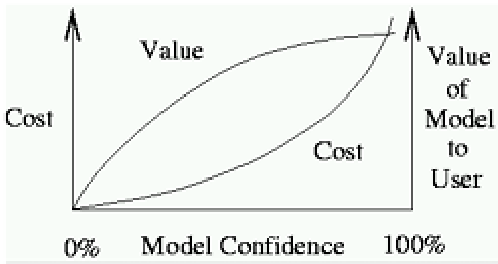
During the validation phase, the outputs of the model are compared to the behaviour of the real system to determine whether the simulation model being used is accurate. Those who designed the model and those who use it, who often make decisions based on the information obtained from the model's outputs, are concerned about the model's accuracy. Those impacted by the judgments are similarly concerned about the veracity of the outcomes.

Model validation is another approach that might be used to address this issue. According to Sargent (2005), if the purpose of a model is to offer answers to a variety of questions, the model's validity must be independently confirmed for each question. Moreover, he feels that a range of unique experimental conditions is often necessary to assess the scope of a model's alleged use. Consequently, a model may be appropriate for one set of experimental circumstances but inappropriate for another. If the performance indicators or output variables of interest fall within an acceptable range for a model, then the model may be considered legitimate for the given experimental conditions. In other words, the permissible range corresponds to the required degree of accuracy for the application for which mode l is designed. In addition, it is essential to emphasize that the required level of precision must be specified either before commencing work on the model or very early in the process.

Regardless of the significance of validation methodologies, it may be prohibitively costly and time-consuming to check if a model is totally valid over its whole application domain (SARGENT, 2005). Instead, testing and evaluations must be conducted until an appropriate level of trust for the application is created. However, asserting that a model is exact enough for a particular set of experimental conditions does not imply that the model is true elsewhere within its range of applicability. Rather, it ensures that the model is appropriate for the experimental conditions supplied. Figure 6 labelled "Model confidence, performance cost," demonstrates the relationship between model validation and the benefit the model provides to an end user. According to Sargent (2005), there are four fundamental validation techniques available. Below is a description of these diverse strategies:

1. Determining the validity of a simulation model is standard procedure for the team responsible for its creation. Various tests and evaluations are conducted as part of the model creation process. The results of these tests are then used to provide an objective evaluation.
2. If the simulation team is small, the model's users must be extensively involved with the team responsible for validating the simulation model's validity. To validate the notion, this approach will shift its focus from developers to consumers.
3. The third alternative is referred to as "independent verification and validation." A third party evaluates the simulation model's reliability independently and outside of the team. Separation from the third party is important for both the team making the simulation and the people who will use it.
4. The last strategy utilizes a scoring model to evaluate the simulation model's precision. Ratings are determined subjectively throughout the execution of the many validation process components. After aggregating these assessments, category ratings and an overall rating for the simulation model are generated. When the model's overall and category scores are above a certain threshold, it is considered valid. Despite this, this technology is relatively uncommon. The link between confidence, cost, and user value is shown in Figure 5.

The model validation process used in this inquiry was based on the second methodology. The development team consisted of a single person. According to Sargent (2005), if the simulation team is small, the validity of the model must be confirmed by carefully including the model's end users. This is necessary to ensure that the model is accurate. In this instance, the development of a user-validated indicator of performance metric was crucial. This performance indicator must match the real system as closely as possible within the range that was set at the beginning of model development.



Source: Sargent (2005)

Figure 5: The comparison in between confidence, cost, and user value

3.8 Indicators of Key Performance

The bus's lead time (total duration) is the company's most important performance metric. Due to the absence of a reliable information system, the organization cannot accurately evaluate this crucial performance parameter. To ease decision-making, it is essential to estimate this statistic, particularly during peak season when the garage is busier.

Understanding the average wait time is essential to comprehend the system's operation. Currently, the company is not tracking this performance metric. This relates directly to the use of inspection pits and other physical assets. Additionally, this performance indicator facilitates the identification of process bottlenecks. There is a 33% association between the time spent waiting and the time it takes for buses to reach their destinations. Value-added time refers to the total time spent on activities that provide value. The number of buses that run on a regular timetable is an additional significant factor (number out).

The number of scheduled buses is influenced by a variety of factors, some of which are random and others seasonal. Despite this, evaluating this indicator by performing a historical analysis over a certain length of time is possible. Therefore, the number of buses expected to be present was chosen as the success metric. It was the only method available to establish a connection between historical facts and simulated outcomes. There are further elements to consider, such as the number of buses and trucks that arrive daily at the port (number in). Several more performance parameters may be used to determine the terminal's capacity. One may see the use of each resource both in real-time and in advance.

According to the research findings, planned utilization is an excellent performance metric since it just needs the number of working hours for each resource. It is essential to evaluate the use of the inspection pits, outside washing platforms, gasoline stations, and cleaning areas. Based on the information provided by the anticipated use of mechanical pits, the company may determine whether it needs to increase its resource allocation to meet future demand growth. This information is crucial since it helps the organization decide whether or not to increase its resource allocation. Due to their participation in not one but two of the most crucial procedures, the mechanical inspection pits are projected to be employed more often than the other resources. This includes both general inspections and the maintenance of mechanical components.

3.9 Comparing Simulated Results to Historical Information

Before continuing with the examination of other potential alternative scenarios, it is essential to demonstrate that the simulation model can accurately replicate the real system's behaviour. In its absence, the results of simulations of hypothetical situations will differ from those of the real system after it is implemented. Using data from the 5th to the 19th of August, a 95% confidence interval was constructed, and the number of scheduled bus performance indicators will be compared to the actual system. This will be done to verify the model's findings. In the absence of a dependable information system, it is also essential to address the difficulties of collecting trustworthy data for certain operations. This is necessary to fulfil certain obligations.

4. Model Development

This section explains the main aspects of the simulation project's conception and design stages. First, an overview of the major processes that take place inside the organization under consideration is presented. The simulation research's scope and restrictions are then specified.

The last section contains a detailed explanation of the model's construction. Finally, each of these processes' resources are specified.

4.1 Process Description

The company under investigation has its primary maintenance hub in the bus garage. The company's routes are planned, vehicle schedules are made, and the headquarters are located in this hub. As previously stated, the garage's capacity evaluation is becoming increasingly important. Its operational capacity has not previously been the subject of statistical research. The identification of potential bottlenecks in the maintenance department is another frequent issue that the company faces. The majority of Trinidad businesses providing this kind of service face this issue frequently.

The company under investigation provides bus transportation services across the country. It serves 7 main stations throughout Trinidad and Tobago. In 1964, the company began operations with the intention of providing first-rate bus service and placing a premium on comfort, quality, and safety in its bus lines. It has a modern fleet of about 270 vehicles, the majority of which are less than ten years old. The company updates approximately 10% of its fleet annually. In order to grant bus availability and identify potential failures, the maintenance department conducts a number of regular inspections on its vehicles. Over 1500 people work for the company.

Buses arrive at the main hub from numerous locations throughout Trinidad. Additionally, it serves as a bus depot with storage space for approximately 350 vehicles. Every day, more than 60 buses arrive for any necessary safety and comfort-related maintenance or inspection. The main processes that take place in the garage are included in the maintenance operations. Cleaning, inspection, and both corrective and preventative maintenance are performed on the buses. The terminal's internal process flow must be defined before the system can be modeled.

Using Arena software, the maintenance operation process was developed.

The arrival of the bus begins the procedure. Delivering the travel form to the driver at the reception is the first step. The bus's information can be found on this form, which the driver should fill out. In the event of failure or damage to the vehicle, the driver must fill out this form to help with the inspection and any necessary repairs. The fuel loading station staff receives the travel form next.

Several processes simultaneously take place as the bus moves toward the fuel station. The bus's mechanical parts are lubricated and the fuel station staff prepares it for fuel loading. The expiration of the filters and the travel form are checked by another employee. In light of the driver's report (travel structure) and on vehicle kilometrage the supervisor opens a help request, which will be sent to the respective department for repairs.

The bus then travels to the department of washing. To get rid of any gross dirt on the bus body, a first exterior wash is done. It is a task that mostly requires labor. For this task, a group of three people is typically employed. In this manner, the vehicle is dislodged to a clothes washer to play out an extra wash. This second wash is required to clean the interior of the bus. The bus immediately proceeds to the inspection pit for regular maintenance procedures if there is free space in the inspection pits. On the other hand, the vehicle is moved to the parking area to wait for a spot in the maintenance department if all inspection pits are full. To indicate the status of the buses, a sign is frequently positioned on their windshields.

When the bus arrives, a worker is liable for relegating it to an inspection pit. He first verifies the kind of service order that was requested. All buses frequently require an overall inspection, which entails passing through a variety of tests, including electrical inspection, AC inspection, tyre inspection, and bodywork inspection are all types of inspection. A new service order must then be opened if there are any preventative or corrective measures. The bus must then be moved to the appropriate inspection pit. As such, on the off chance that a transport needs to play out any remedial or preventive activities it requirements to move starting with one division then onto the next relying upon the assistance type**. Figure 7** is provided to make it easier to visualize the garage's actual layout.

The bus is prepared to move on to the final stage when it has completed all maintenance procedures. The vehicle is then subjected to a final inspection to ensure that neither the client's personal belongings nor any dirt from the previous trip are inside.

The company works 24 hours per day, from Monday to Sunday. During the week, bus demand typically fluctuates due to a number of factors.

Even though the garage is open around the clock, the internal processes, tasks, and procedures do not operate at the same capacity throughout the day. For instance, because of the decreased demand and increased costs of labour, some processes are unable to function during the night shift. There is a schedule for each process. The following sections will provide a comprehensive explanation of these schedules.

4.2 The Scope and Structure of the Simulation

Simulation modelling is frequently linked to abstraction and simplification. Because simulation is frequently motivated by financial and time constraints, it is essential to define the appropriate level of abstraction. It is likely to be inefficient in terms of time and money if the model's goal is to accurately represent the real system. A model's level of abstractness was previously discussed.

This study tries to represent the vehicle preparation and maintenance procedures among all garage activities. Financial support, accounting, human resource management, inventory management, resource management and sourcing, traffic planning, schedule planning, and other processes take place in the company's main hub. The activities of maintenance and preparation were chosen because they represent the company's core operations. Due to the influence these activities have on the client's perception of added value, ensuring the availability of the buses, the comfort of the passengers, and system safety are essential to this kind of business. To aid in the decision-making process, it is therefore essential to comprehend the terminal's capabilities.

The ability to configure the model to observe the system in a variety of situations and scenarios is one of the primary objectives of this study. Another is to represent the actual system in such a way that the processes' times and performance measures obtained through simulation reach close values in relation to the actual observations. There are a few activities that were not modelled because of the system's high complexity. This is due to the significant increase in the final model's financial and time costs, which would likely render the model ineffective rather than useful. During the process of modelling the system, a few presumptions and simplifications were used. The following is a description of the assumptions:

a. Demand variations influenced by external factors are not taken into account by the model, such as: holidays, the season, the availability of buses, and other factors. The bus demand was divided into time intervals and estimated using actual observations.
b. It is assumed that bus demand increases are proportional. The proportions of the times between arrivals remain constant for each time segment, making them easy to model with the same probability distributions. To put it simply, all that is required is to multiply the times between arrivals by a constant.
c. The model does not take into account sporadic system failures like fuel pump failures, fuel quality inspections, interruptions in washing machine maintenance, breakdowns, and other events that only happen occasionally.
d. A First-Come, First-Served (FCFS) allocation policy is assumed to be followed by the buses. To put it another way, the arrival order of the buses determines which pits the buses are sent to for inspection. In order to allocate the buses to the inspection pits, the model does not take into account their schedules.
e. In this model, the transfer times between processes are not taken into account. The time it took to move from the reception to the fuel station, from the fuel station to the exterior washing, from the exterior washing to the interior cleaning, from the interior cleaning to the inspection pits, and from one inspection pit to another was not taken into account. Because they have no real effect on the operations, these times can be ignored. They are also difficult to measure because they are susceptible to variations.

4.3 Model Construction

In this section, the model's development process is discussed. The important parts of the models and the methods used to simulate facility operations are described in detail in the following sections. First, the procedure for getting on the bus is discussed. Data collection procedures, demand variations, and probability distributions are all explained in detail. Second, the fuel fulling is discussed. Thirdly, the characteristics and model structure for exterior washing operations are included. Fourthly, the interior cleaning procedure and approach are described. The maintenance department's procedures are then discussed. It encompasses the inspections of the vehicle's mechanical, electrical, AC, tyre, planned maintenance and bodywork, in addition to the services provided by each of these sectors. In order to make it easier to comprehend the model conception, tables, charts, diagrams, and figures are provided.

4.3.1 Bus Arrival

It was necessary to obtain information regarding bus arrival times over the previous few months in order to simulate the bus arrival event. However, the company's database did not contain bus arrival times. The employees at the fuel station who were in charge of lubrication and fuel loading completed a document known as the "fuel consumption record." The time that each bus arrives at the fuel station is listed in this document. Since bus arrivals at the fuel station were more realistic than those at the reception, the model was calibrated accordingly. Because the travel distance between the main entrance (reception) and the fuel station (first process) can be ignored, this abstraction was necessary.

From the fuel consumption record, a sample of 11 days was taken. The company's archive was the source of these data. All of the data in the documents was entered manually. In order to use the data in the model, it was then necessary to move it to a spreadsheet on a computer. 307 arrival times were extracted and transferred in total. Then, the data was handled to acquire some knowledge about the way of behaving of the framework. The day was broken up into three time of roughly eight hours each in order to make it easier to understand the events surrounding the bus arrivals. The intervals of time are as follows: interval 1 (between

0:00 and 07:59); interval 2 (between 8:00 and 3:59 p.m.) and interval 3 (between 4:00 and 11:59) It's also important to point out that the data were taken from a month that was typical. The selected eleven-day period spans from August 8th, 2022 to August 19th, 2022. This time period was chosen because there were no public holidays or special events, so it is expected that people will behave normally. Table 2 shows the complete number of appearances for every day.

Table 2: Total Number of Arrivals

DAY	TOTAL NUMBER OF ARRIVALS
08/8/2022 (Monday)	58
09/08/2022 (Tuesday)	57
10/08/2022 (Wednesday)	65
11/08/2022 (Thursday)	56
12/08/2022 (Friday)	63
13/08/2022 (Saturday)	30
14/08/2022 (Sunday)	34
15/08/2022 (Monday)	60
16/08/2022 (Tuesday)	57
17/08/2022 (Wednesday)	56
18/08/2022 (Thursday)	54
19/08/2022 (Friday)	62
TOTAL	652

During the course of this study's development, it became clear that bus arrival rates significantly varied throughout the day. The model outputs would not be satisfactory if this variable were considered constant because it would be impossible to observe the effects of overload and idleness during the day. Variation in demand is the cause of these effects. For attainable outcomes, it is essential to comprehend this concept.

First, variations can be identified during the week. It is anticipated that a particular behaviour will occur from Friday to Monday. Normally the garage is more occupied during Monday to Friday because of the way that the transports ought to be working during the week, when the interest is higher. On August 8, 9, 10, 11 and 12, this behaviour can be observed. To outline what is happening, **Figure 8** shows the appearance rate variety of transports for each time timespan period previously mentioned.

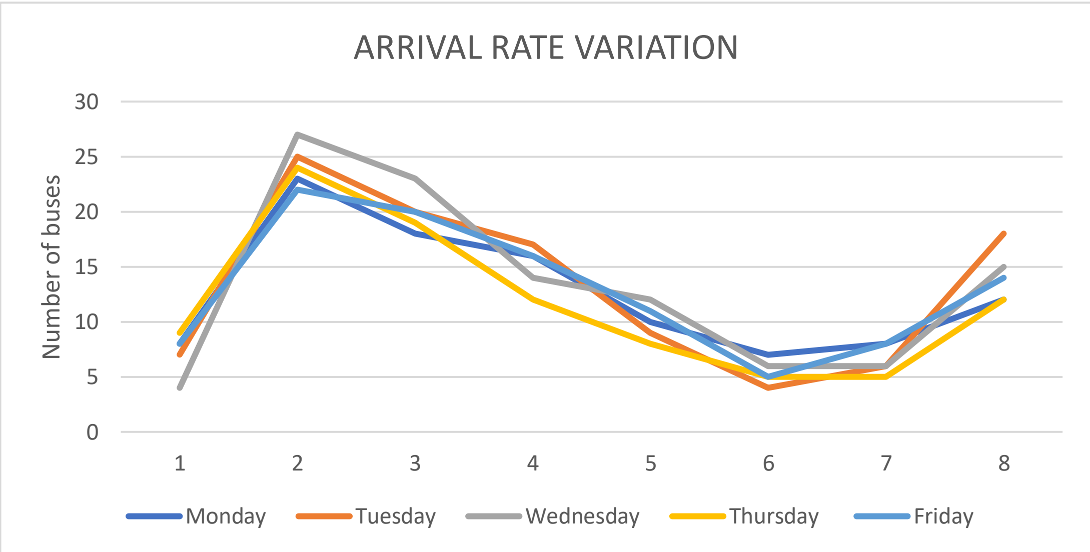


Figure 8: Arrival Rate Variation

Based on Figure 8, it is also feasible to see the variation in bus arrival rates during the day. There are certain traits that are very similar. First, compared to other intervals, interval 1 (from 00:00 to 02:59) often has lower arrival rates. Then, up until interval 3 (from 06:00 to 08:59), the arrival rate tends to rise. Because most buses conclude their operations at night and head back to the garage early in the morning to perform maintenance tasks, a greater arrival rate is anticipated in the morning. The arrival rates then begin to drop until intervals 4 or 6, then start to rise again until interval 8, at which point the cycle repeats.

4.3.2 Fuel Station

The initial procedure at the garage takes place at the fuel station. The personnel accountable for this procedure are required to replenish the fuel tank of the buses. An additional significant function carried out at the fuel station pertains to the examination of the mode of transportation. Upon analyzing the travel form, it is necessary for the responsible employee to initiate a service order for the purpose of conducting a maintenance inspection. Upon initiation of a service order, it is dispatched to the maintenance department for further processing. The maintenance personnel are then tasked with the responsibility of designating the buses to their respective inspection pits.

The organization doesn't have any control over the operational schedule for the duties executed at the fuel station. Subsequently, it became imperative to quantify the durations of each individual operation. The simultaneous occurrence of multiple processes led to the adoption of a time measurement approach that accounts for the duration between the bus's arrival and departure from the station. A sample size of 40 was utilized in the study. The samples were manually measured using a stopwatch during the morning period, a time when the volume of bus traffic typically increases. Subsequently, the duration of each sample was transcribed onto an electronic spreadsheet for the purpose of being interpreted by the Input Analyser. It is noteworthy to state that the probability distribution successfully passed the Kolmogorov-Smirnov test with a p-value exceeding 0.05. **Figure 9** illustrates the ultimate outcome of the probability distribution employed to simulate the operations of the fuel station.

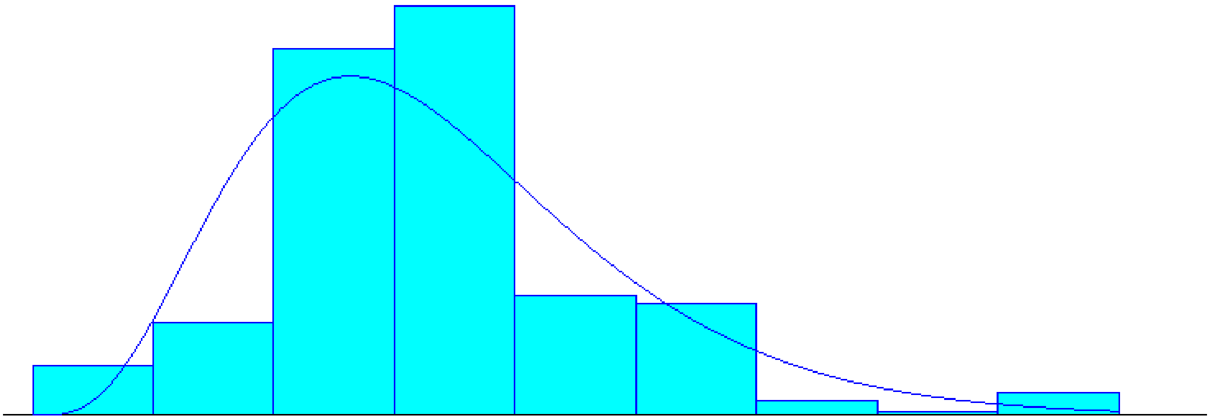


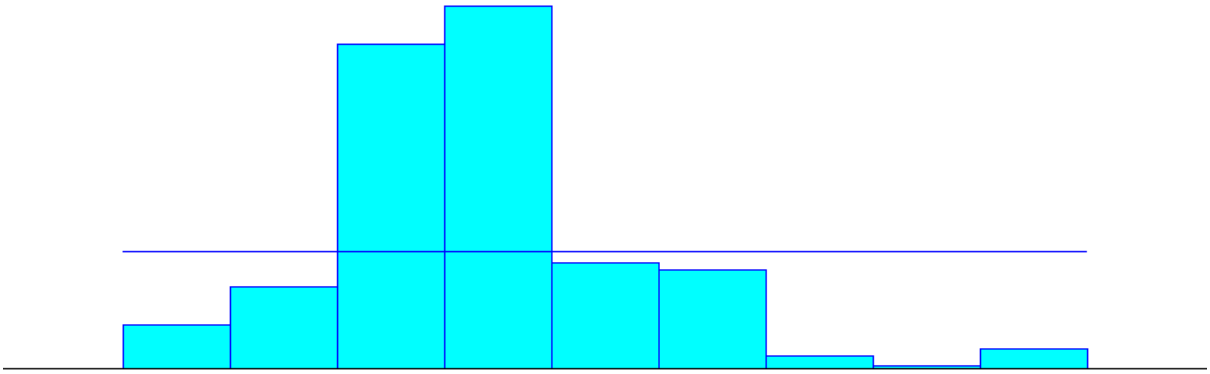
Figure 9: Gamma Distribution for the Fuel Station Process

The process module was utilized to simulate the activity. The purpose of this module is to serve as the primary method of processing for a simulation project. There exist alternatives for the acquisition and liberation of resource limitations. Subsequently, the module was configured to execute a seize delay release mechanism, and the probability distribution illustrated in Figure 10 was ascertained as the temporal delay function. The probability distribution's expression is formally defined as 0.5 + GAMM(0.724, 4.63).

4.3.3 External Washing

The subsequent procedure that takes place at the garage transpires at the exterior washing platforms. The personnel accountable for this procedure are required to execute multiple duties to eliminate the unsanitary residue found on the buses. Upon arrival of the bus at the external washing platform, a staff member promptly initiates the cleansing process by utilizing a foam hose to wash the windshield and body of the vehicle. Subsequently, an additional staff member proceeds to access the engine compartment with the intention of removing any soiled component. Upon completion of these procedures, it is necessary to thoroughly cleanse the bus. Ultimately, the diligent team is required to complete the task of cleansing the tires.

Notwithstanding the significance of this procedure in shaping the customer's perception of value addition, the company failed to regulate the duration of operations for the tasks carried out at the external washing platform. It was imperative to quantify the duration of each task. Multiple tasks are concurrently taking place on the exterior washing platforms. Typically, the conscientious team divides the duties to minimize the overall duration of the procedure. Henceforth, the duration encompassed the interval between the bus's arrival at the platform and its departure. A sample size of 30 was deemed to be comprehensive. The samples were measured manually using a stopwatch during the morning period, a time when bus flow typically increases. Similar to the preceding procedure, the duration of every specimen was exported to a spreadsheet to enable the Input Analyser to interpret the data. The selected



probability distribution has been deemed acceptable based on the results of the Kolmogorov-Smirnov test, which yielded a p-value exceeding 0.05.

Figure 10: Weibull Distribution for the External Washing Processes

Subsequently, the operation was simulated through the utilization of a process module. The process module has been configured with an action of size delay release. The delay time for the process is defined by an expression expressed as UNIF (0, 0). The probability distribution utilized to simulate the operational duration of tasks executed at the external washing platforms is illustrated in **Figure 10.**

4.3.4 Internal Cleaning

The ultimate step prior to the allocation of the bus to the maintenance department is executed at the washing station. The interior of the bus undergoes a cleaning process that involves wiping, sweeping, and mopping. Additionally, waste receptacles are emptied.

The organization's tracking system provided a set of 30 samples that included the recorded time of each wash. The samples encompass the duration of the bus's cleaning process, from initiation to departure from the station. The maintenance engineering team conducted manual measurements on the samples. The process of modeling adhered to the identical procedure expounded in the preceding two sections. The selected probability distribution was found to have a p-value greater than 0.05 upon undergoing the K-S test.

The process module was utilized to model the aforementioned activity. The expression produced by the Input Analyser of ARENA is delineated in the subsequent manner: 0.5 + WEIB(3.77, 2.39). The aforementioned phrase was employed as the duration of the postponement period for the sanitation procedure. The process module was configured to perform a seize delay release action. The probability distribution that was utilized is depicted in Figure 11.

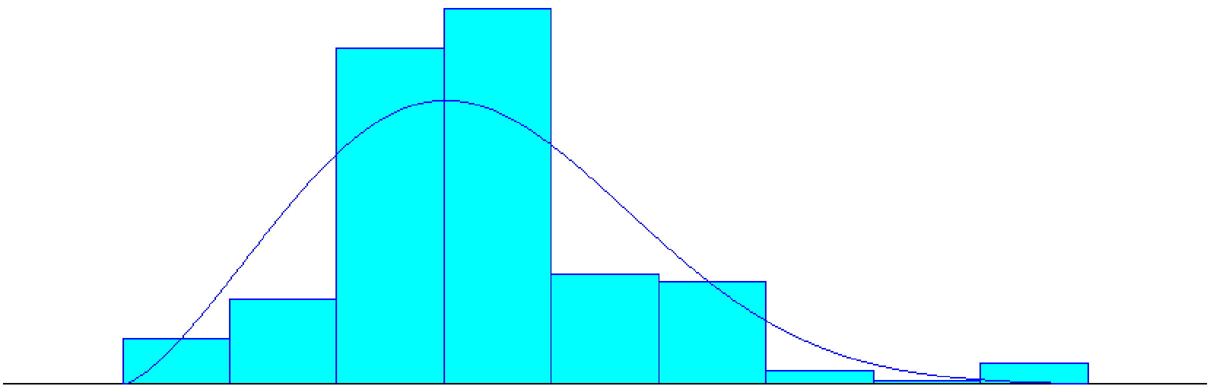


Figure 11: Gamma Distribution for the Washing Machine Process

4.3.5 Inspection Pits

Inspection pits are structures designed for the purpose of facilitating the inspection of vehicles or other equipment from below.

Following procedures related to lubrication, fuel loading, and cleaning, the buses are prepared for transportation to mechanical pits for a comprehensive inspection. The individual responsible for managing the garage is tasked with receiving the service orders for inspections that were previously initiated at the fuel station. The task of allocating buses to inspection pits falls under his responsibility. The layout of the maintenance department is depicted in Figure 12. There exist three mechanical inspection pits. The aforementioned cavities are utilized for both routine examination and the execution of remedial and anticipatory upkeep tasks.

Upon arrival of the bus at an inspection pit, a team comprising of specialists in various maintenance domains conducts a comprehensive assessment of the vehicle's condition. The teams consist of maintenance professionals who endeavor to detect any potential malfunction, anomalous operation, or impaired components in the AC, electric, bodywork, and mechanics domains. The inspection procedures are consistently carried out at the mechanical pits. The aforementioned process holds significant importance as it has the ability to identify malfunctions, thereby impacting critical performance metrics such as safety and vehicle accessibility, which are pivotal factors in shaping the customer's perception of value addition.

A sample size of 392 inspections was extracted from the maintenance management software of the company to facilitate the modeling of the process. The data was transferred to the Input

Analyser of ARENA. The analysis for the time recorded at the inspection pit is presented in Figure 12.

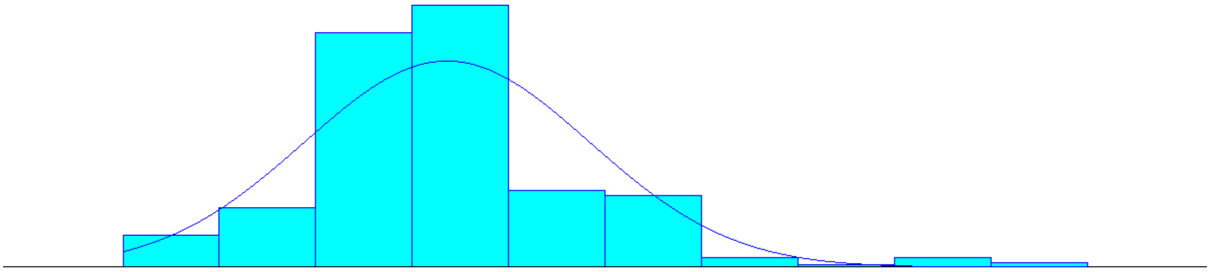


Figure 12: Recorded Time of Inspection Pit

4.3.6 Maintenance Service

Maintenance services refer to the activities and tasks performed to ensure the proper functioning and upkeep of a particular system, equipment, or facility. These services may include routine inspections, repairs, cleaning, and replacements of parts or components as needed to prevent or address any potential issues or malfunctions. Effective maintenance services are critical to ensuring the longevity and optimal performance of the system or equipment in question.

In the event of unforeseen conduct or vehicular malfunction, it is imperative to execute remedial and preventative maintenance measures. Frequently, problems are identified during the examinations conducted at the mechanical pits. As previously stated, the maintenance services offered by the organization are categorized into four distinct groups based on the nature of the malfunction: mechanical, electrical, AC, and bodywork. As depicted in Figure 12, every category of service is associated with a distinct department and a finite quantity of examination pits.

Service Type	Probability Distribution	Proportion of vehicles assigned to process (%)
Mechanical	Continuous	67.92
Electrical	Triangular (15.0, 45.0, 300.0)	15.09
Refrigeration	Triangular (60.0, 90.0, 300.0)	9.40
Upholstery	Triangular (30.0, 45.0, 120.0)	1.89
Bodywork	Triangular (60.0, 100.0, 120.0)	10.69

Table 4: Probability Distributions and Proportion of Vehicles Assigned

To simulate the implementation of maintenance services, it was imperative to determine the ratio of buses that are diverted for this purpose. Initially, a retrospective analysis was conducted on a 12-day time frame of historical data encompassing all maintenance services performed between the dates of August 8^{th} and August 19^{th} in the year 2022. Based on the available data, an estimation was made regarding the overall quantity of buses that required either preventive or corrective measures. The reports derived from the maintenance management system included details pertaining to the nature of the service that was executed. A survey was carried out with the maintenance staff to establish the distinct categories of services. Following the classification of services, the allocation of vehicles to each process was determined by computing the percentage of service orders received during the relevant period. The construction of the model involved a series of process and decide modules. The decision modules were randomly configured as two-way, while the process modules were tailored to the specific attributes of each respective activity. Following the analysis, it was determined that a maintenance service is required for 75.67% of the buses. The study concluded by specifying the proportion of vehicles necessitating each category of maintenance service, along with the probability distributions utilized for simulating the process time. The estimation of processing times for electrical, AC, and bodywork activities was conducted through interviews, as the company did not have a system in place to monitor these durations. The estimation of mechanical services was conducted using data obtained from a computerized management system, with a sufficient number of samples. Table 4 displays the probabilities and proportions of vehicles allocated to each maintenance service.

4.3.7 Cleaning Services

The ultimate procedures that transpire within the garage encompass cleansing protocols. The aforementioned procedures are performed within a demarcated region, as illustrated in Figure 13. There exist two distinct categories of tasks that require execution. Initially, it is imperative to perform interior cleaning of the buses. The cleaning process involves the sanitation of various interior components such as seats, dashboard, windows, curtains, and other related elements. Additionally, the exterior undergoes a cleaning process. Particular attention should be paid to the luggage compartment, windshield, exterior windows, and tires.

The processing module was utilized to simulate these activities. Two modules were established, each with its corresponding probability distribution, for the purpose of simulating the execution times of individual procedures. Table 5 outlines the attributes of the probability distributions. It is noteworthy to state that the data was obtained from the monitoring system of the organization.

Process	**Probability Distribution**	**Sample Size**	**Max/Min. (Minutes)**	**Standard Dev.**	**P-value (K-S Test)**
Interior Cleaning	0.5 + WEIB (3.77, 2.39)	307	0/8	1.46	P< 0.005
Exterior Cleaning	UNIF (0,0)	307	0/8	1.46	P< 0.005

Table 5: Probability Distributions for Cleaning Services

4.3.8 Resources

It was necessary to determine the number of resources required to complete each activity in order to determine the capacity for each process. Important details like whether the capacity is constant or fluctuates based on a timetable should be defined. Another option is to compel the resource to fail in a predetermined pattern. Failures were not included in this study; only schedules were. The characteristics of the resources used in the model are detailed in Table 6.

Due to their constant operation, the loading platform and the washing machine have a set capacity. According to the schedule, it was also regarded as the one-hour lunch break between 12:00 and 13:00. The schedule rule was configured to "pre-empt" in longer operations, such as those that take place in the pits. The "wait" option instructs the model to delay beginning the real capacity drop until the in-process entities have released all of the resource's units. The "pre-empt" alternative, on the other hand, seeks to prevent the final unit of the resource from being taken by removing it from the controlling entity (KELTON; SADOWSKI; SWETS, 2007). Appendix B contains a visual representation of the complete model, including all of its modules, processes, and resources.

Resource	**Operations**	**Type**	**Capacity (Units)**
Fuelling Bay	Fuel Loading	Fixed Capacity	2
Internal Cleaning	Internal Cleaning	Fixed Capacity	0
External Cleaning	External Cleaning	Fixed Capacity	1
Mechanical Pit	Mechanical Services	Based on Schedule	4
Electrical Pit	Electrical Services	Based on Schedule	1
AC Pit	AC Services	Based on Schedule	1
Bodywork Pit	Bodywork Services	Based on Schedule	1
Tyre Service Pit	Tyre Services	Based on Schedule	1
Preventative Maintenance Pit	Preventative Maintenance Services	Based on Schedule	1

Table 6: Resource List

5. Results and Discussion

The outcomes of the simulation trials are thoroughly explained in this chapter. The true simulated scenario is tested first, and the outcomes for the performance indicators and the queue formation procedure are displayed. Then, a different scenario is confirmed using more examination pits. Four mechanical pits were used as an additional number for the simulation. Evaluation is done of the effects on queue formation, capacity, and performance indicators. The effectiveness of the system is then evaluated for various numbers of mechanical pits in order to estimate the advantages of a possible expansion project. Finally, another scenario is evaluated while taking into account the redistribution of bodywork pits from tyre service pits.

5.1 Simulation Results

The overall outcomes of the simulation model following the validation procedure will be covered in this subsection. First, it's critical to comprehend the difference between the two categories of performance indicators. The first one has to do with the actual entity as well as a fixed time variable. This variable is linked to how the entities behave. The buses are the only thing that exists in this study. As entity linked indicators, these performance metrics were described.

The second one is about how resources are used. The process modules of the simulation project are always linked to the resources. As was already noted, it is possible to establish both scheduled and immediate utilisation for these resources. Some resources have fixed capacities because they have set schedules, whereas others operate around the clock. These performance metrics were described as indications of resource use. Table 6 previously provided a summary of the resources and their features.

5.1.1 Performance Results for Entity Related Indicators

Only entity-related indications that are linked to a predetermined time variable are discussed in this subsection. These performance indicators are beneficial to the organization since they enable future planning and process efficiency review. It's vital to note that the organization requires a minimum of three and a half hours on average for each bus to complete all tasks in the garage. The performance indicators specific to the entity itself are another addition. These performance indicators include the work-in-progress (WIP), the number in, and the number out. Table 7 provides a description of the simulation model's outputs.

Performance Indicator	Average 95% Confidence Level (hours)	Half Width (hours)	Minimum Average (hours)	Maximum Average (hours)
Value- added time	1.47 (1.07, 2.03)	0.12	0.60	23.09
Wait time	1.22 (0.40, 2.51)	0.20	0.00	15.59
Total time	2.69 (1.57, 4.30)	0.22	0.73	23.14
Number in	65 (65,65)	0.00	-	-
Number out	28 (22, 39)	1.45	-	-
WIP	30.19 (20.98, 37.93)	1.25	0.00	52

Table 7: Performance Outputs for Entity Related Indicators

It can be seen from the table above that the average total time of the model's entities is almost twenty-three hours and one minute, which is the time restriction set by the organization. The simulation closely mimics the behaviour of the real system if the 95% confidence interval is used. Regarding the number of buses, there is yet another crucial factor to take into account. As was already said, this total also reflects the number of buses that depart from the terminal each day. The maintenance engineering team claims that these results accurately reflect the behaviour of the actual system.

The length of the wait is still another crucial factor. For the organization under examination, this performance metric is crucial. To assess the effectiveness of the operations and spot any bottlenecks during the peak season, it is critical to estimate these quantities.

The value-added time refers to the amount of time that the entities spend engaging in value-adding activities. The organization wants to keep the value-added time as close to the overall average time as possible. Additionally, since the organization in issue provides services, it's critical for efficiency that the value-added time be longer than the wait time.

5.1.2 Performance Results for Resource-Related Indicators

One of the main undertakings of the model is to evaluate the limit of the office under study. In a genuine situation, it is feasible to see that the mechanical pits are the most active of the assets. This happens because of the way that two of the main tasks depend on them, which incorporate the general investigations and the mechanical administrations. The interest for these assets is normally higher than others. Figure 17 portrays the asset use and Table 8 shows the outcomes:

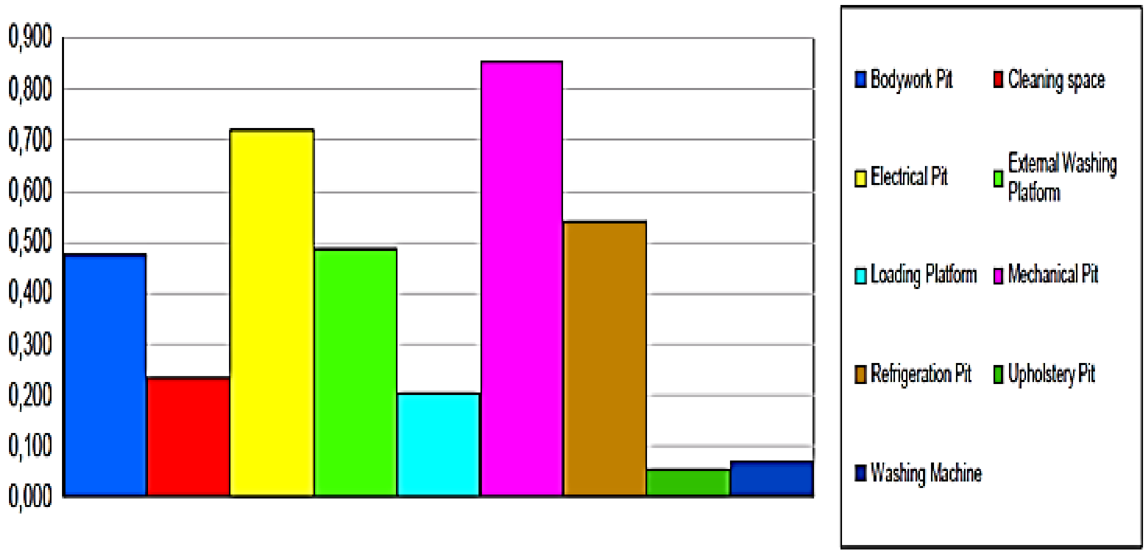


Figure 17 - Resource Utilisation

Resource	Average	Half Width	Minimum Average	Maximum Average
Body Pit	0.47	0.12	0.60	0.08
Cleaning Spaces	0.22	0.20	0.00	0.05
Electrical Pit	0.69	0.22	0.73	0.07
External Washing Platform	0. 65	0.00	0.03	0.03
Loading Platform	0. 28	1.45	0.07	0.04
Mechanical Pit	0. 30	1.25	0.00	1.00
Refrigeration Pit	0.53	0.07	0.06	0.05
Upholstery Pit	0.08	0.06	0.02	0.06
Washing Machine	0.09	0.08	0.05	0.07

Table 8 - Scheduled Utilisation of Resources

The mechanical pits are the assets with the main usage rate. The typical booked usage comes to 85% with a base normal of 70% and a greatest normal of 100 per cent, and that implies it is over-burden during certain times of the day.

To have a better comprehension of these boundaries a graph containing the usage of the mechanical pits throughout the day is given in Figure 18.

Figure 18 - Mechanical pit utilisation over time

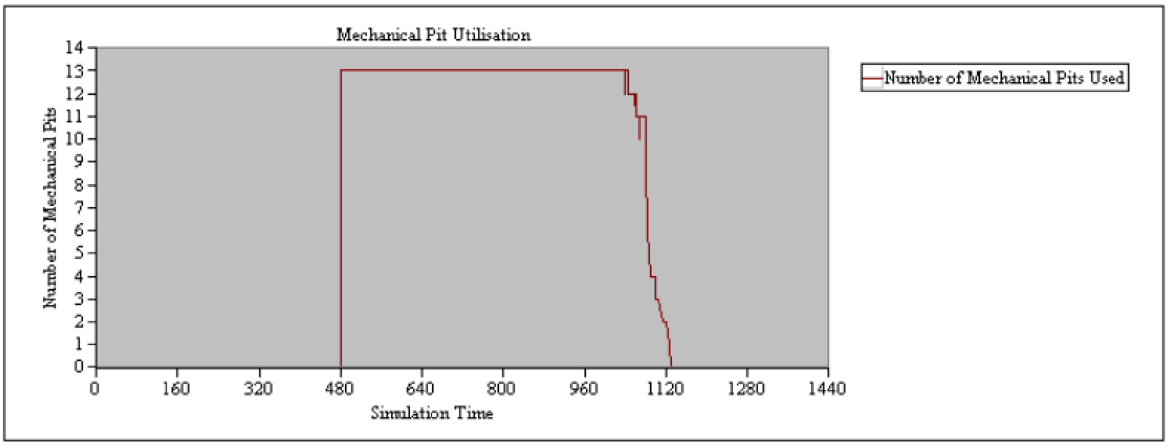


Figure 18: Mechanical Pit Utilisation over Time

Figure 18 was separated from a simulation run. It shows the quantity of mechanical pits used during a one-day time frame. It is feasible to see that the mechanical pits are being utilized in full limit from the outset of the work shift to a second near the end, when the usage starts to diminish definitely. On the following day, another line is framed for once more, assessment and execution of mechanical administrations, keeping the usage rates high. Theorganization is working in full limit right now. Thus, it means quite a bit to search foroptions to lessen the usage of the mechanical pits to support future request increments.

One more asset with high usage rates are the electrical pits. This might occur because of the successive event of electrical issues. These issues shift as indicated by a few factors. In any case, kilometre and the age of the transports are two of the principal reasons. To handle this issue, the organization attempts to keep up with the armada with a typical period of just two years. Later two years, the transports begin to require more support administrations, which can influence the tasks of the organization.

Different resources keep up with satisfactory degrees of usage, like the bodywork pit, refrigeration pit, external washing platforms, cleaning spaces and fuel loading platforms. Notwithstanding, a fundamental variable to consider is using washing machines and upholstery pits. The low usage level of washing machines might happen in light of the quick execution times and their high accessibility. Then again, the upholstery pits follow a ten-hour plan however are seldom utilized.

5.1.3 Queues

The organization under study is keen on deciding the normal time in line for two basic cycles. The first worries the queues for the external washing platforms. The handling season of the outside washing is significantly higher than the past course of fuel loading. During the morning, it is normal to shape queues between the fuel station and the external washing platforms. The other one respects the review pits line. Because of the great number of vehicles during the morning (start of the work shift), it is successive that transports should be relegated to the leaving region to hang tight for a free space at the mechanical pits. The typical time in the line to play out the external wash, as well as the reviews, are separately portrayed in Figures 19 and 20.

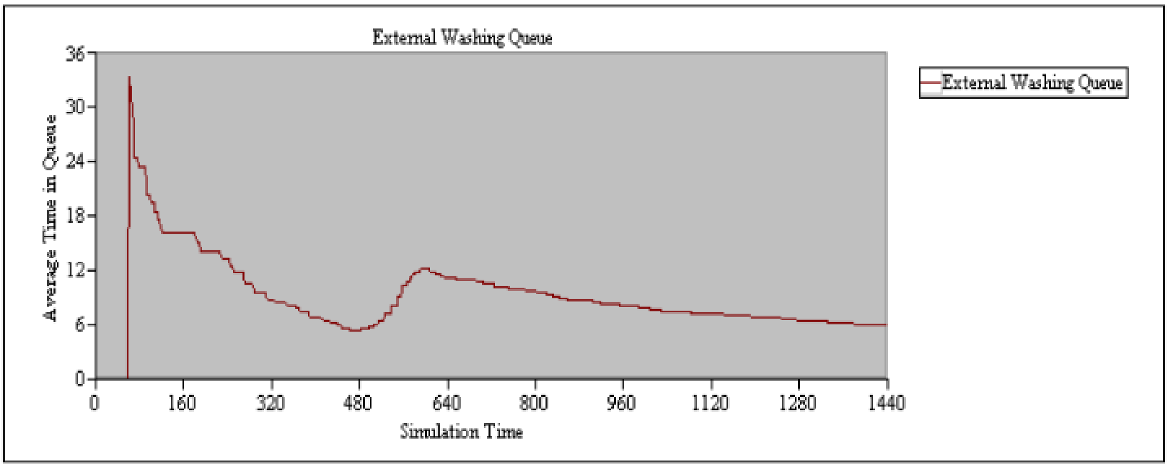


Figure 19: Average Time in External Washing Queue

From Figure 19, the holding-up times are more prominent at 01:00, when the external washing platforms begin to work. It ought to be thought about that any excess transports from the last day and the ones that show up before one o'clock are as of now pausing. The typical time begins to diminish until roughly 08:00 when the appearance rates are higher. Despite the fact that it keeps an adequate rate during the remainder of the day. From Figure 20, it is obvious to see that the typical holding-up time is higher during the start of the work shifts on the grounds that the transports that show up prior are ready to be allotted to an accessible pit. Then, at that point, the typical time will in general diminish over the course of the day. The typical time and number of holding-up units in the queues are displayed in Table 9.

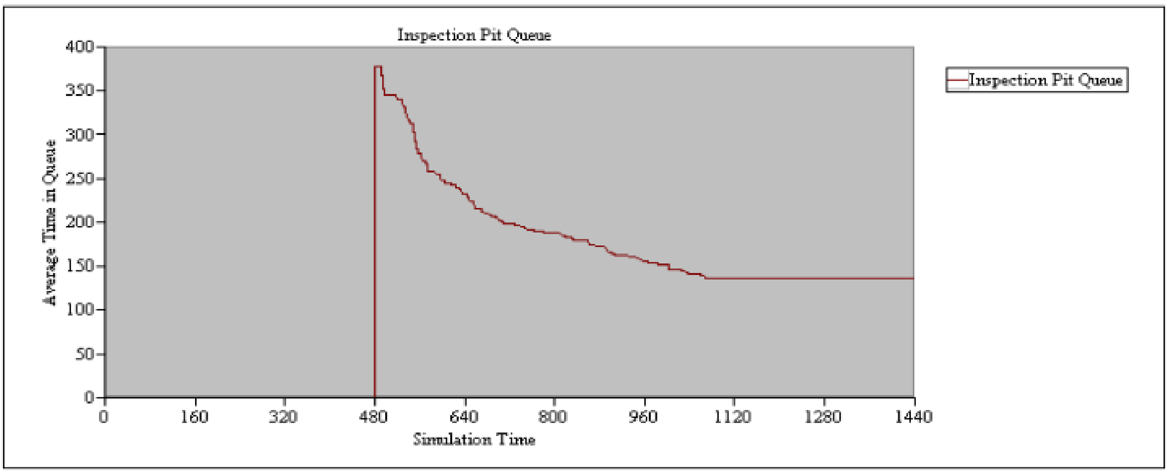


Figure 20: Average Time in Inspection Queue

Queue	Average Waiting Time (Minutes)	Average Waiting Time (Units)
Inspection Pit	15.69	0.22
External Washing	2. 65	10.70
Bodywork Services	14. 28	0.45
Electrical Services	50. 30	2.25
Refrigeration	26.53	0.07
Upholstery	51.08	3.06
Mechanical	0.50	7.08

Table 9: Queue Performance Evaluation for Real Scenario

5.2 Alternative Scenario: Increasing the Number of Inspection Pits

As mentioned in the last section, the use of examination pits arrived at high qualities. To test the effect of the exhibition markers recently mentioned, the model was set to work with an unexpected number of mechanical pits. The all out number of mechanical pits was expanded from 13 to 17. The mechanical pits were decided because of the way that two of the main tasks rely upon them (generally speaking reviews as well as the execution of mechanical administrations). The consequences of the presentation estimates will be depicted and contrasted and the genuine framework in the accompanying subsections.

5.2.1 Performance Results for Entity-Related Indicators with the Increased Number of Mechanical Pits

To start with, it will be discussed the effect of substance related markers. An examination with the outcomes displayed in Table 7 is essential to break down various way of behaving of the genuine framework and the demonstrated situation. With an expanded number of mechanical pits, it is expected to see adjustments for the most part in the exhibition in the time related execution measures, for example, lead time, esteem added time, and stand by time. Another significant thought respects to the number in, number out, and WIP execution measures, which are expected to stay comparative.

5.2.2 Performance Results for Resource Related Indicators with the Increased Number of Mechanical Pits

One more significant situation to test is comparative with the usage of resources later adding 4 new mechanical pits. The usage of the mechanical pits is expected to drop since the quantity of transports continues as before. To reach a few determinations about the use of the mechanical pits, Figure 21 is given.

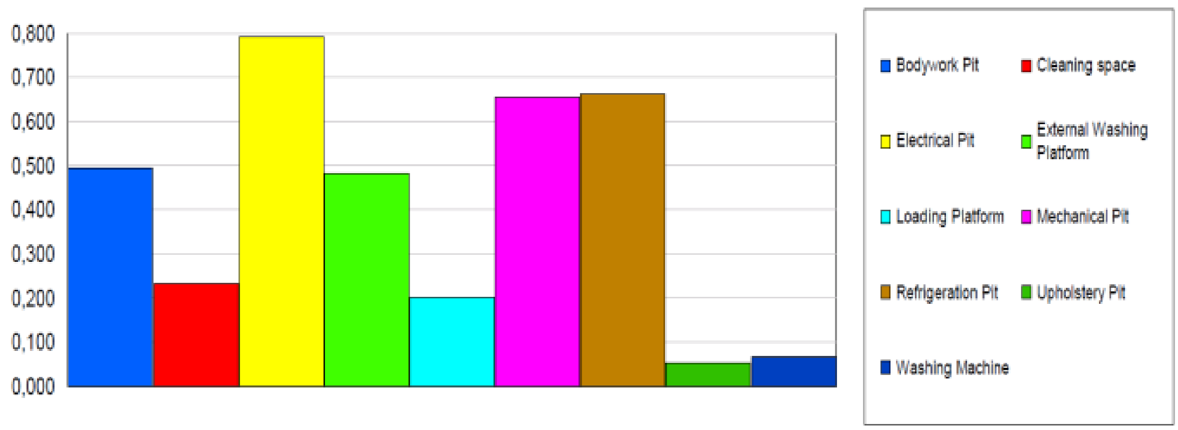


Figure 21 - Resource Utilisation with Increased Number of Mechanical Pits

The reduction of the scheduled use permits the organization to cradle any extra demand all the more easily. Nonetheless, it is costlier to gain and keep an unexpected number of resources. For this situation, a particular examination ought to be directed to assess whether the obtaining of new mechanical pits is valuable to the organization under study. To understand the scheduled use conduct of the elective situation during the day, Figure 22 is given.

5.2.3 Queues with the Increased Number of Inspection Pits

Subsequent to setting adding four new mechanical assessment pits, it is expected the reduction in the complete holding up time. Thus, the line arrangement cycle ought to be decreased in examination with the genuine situation. As mentioned before, evaluating the exhibition of two most significant queues is significant. The line at the external wash as well as the one for examination. Figure 22 and 23 portray the typical time in line for external wash and examination.

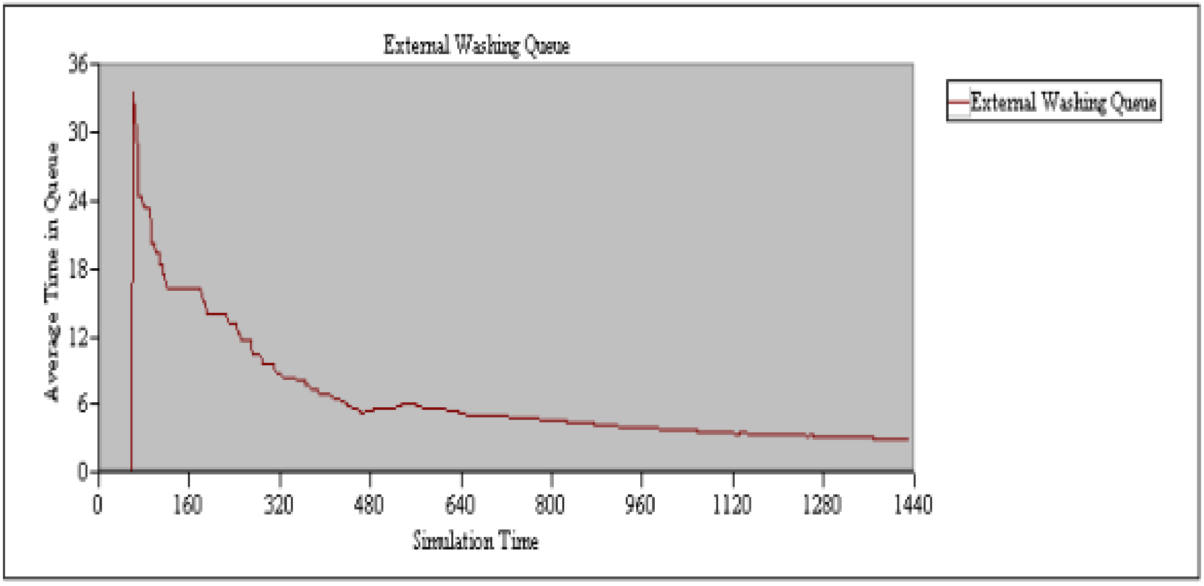


Figure 22: Average Time in External Washing Queue with Increased Number Of Mechanical Pits

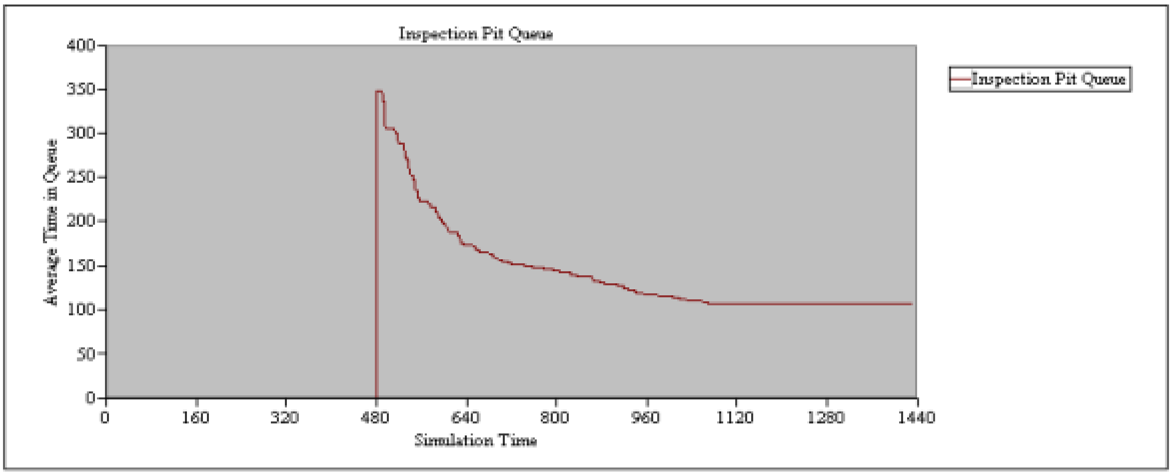


Figure 23: Average Time in Inspection Queue with Increased Number of Mechanical Pits

From Figure 22, it is feasible to reason that the typical time in the line has decreased in contrast with the real scenario. A significant change is seen when the simulation run arrives at 480 minutes when the appearance pace of transports is strengthened. In the real scenario, the typical holding up time begins to increment and arrives at a pinnacle of 12 minutes of delaying time at 640 minutes of the simulation run. In the meantime, in the elective scenario, the typical holding up time is around 6 minutes and will in general consistently decline a while later.

The main changes happen in the assessment pit line, which is addressed in Figure 23. In correlation with the real scenario, there is a reduction of roughly 35 minutes in the normal time in the line at 480 minutes of the simulation run. Then, the way of behaving of the bend will in general be something very similar, notwithstanding, the typical stand by time is extensively decreased.

5.3 System Behaviour for Different Numbers of Mechanical Pits

Another practical choice to check the way of behaving of the framework is to decide the varieties of execution measures for various scenarios and assess which conditions give the best outcomes. Hence, it was important to assess the upsides of these actions thinking about various quantities of resources. As recently expressed, the mechanical pits were decided because of the effect that they create in the presentation proportions of the framework.

5.4 Testing the Reallocation of Resources

From the scenarios recently tested, there is an unmistakable variety in the use of resources. For instance, the scheduled usage of upholstery pits is ordinarily the lower one, which is as a rule around 5%. This kind of administration is seldom performed at the carport. Another method for testing the effectiveness of the activities is to reallocate resources with more prominent demands to less used ones. For this situation, it is feasible to assess whether it is worth or not to reallocate the upholstery pits. In other words, the exercises that occur in the upholstery pits can be changed to fit the additional demand that over-burdens the mechanical pits. For this situation, there was a replacement of the 2 upholstery pits for mechanical ones.

6. Conclusion

It was feasible to build a mechanized model that steadfastly addresses the real framework through a steady examination of the support tasks that happen inside the carport. The cycle modules required a lot of information gathered straightforwardly in the organization through the upkeep of the executives software, hand-filled information, or meetings led by the support designing staff. The model advancement stage included the use of different ideas and devices tended in the field of simulation and functional exploration. It was fundamental to adjust the reality of the transport carport to the rationale of the electronic model in view of the discrete-occasion simulation. The model was sufficiently hearty to repeat the upkeep activities and, simultaneously, improved to make its advancement attainable as well as to run the important replications in Field effectively.

Various scenarios were tested to investigate the likely changes in the way of behaving of the real framework and the impacts over functional execution. It was checked that the additions in the quantity of mechanical pits is certainly the best option regarding gains, particularly for the quantity of 17 mechanical pits (the effects over element and asset based markers were estimated exhaustively for this number) as well concerning 18 pits. The reduction in the scheduled usage becomes blank for 19 and 20 pits (these outcomes are shown in Figure 26). For the lead-time the way of behaving is comparative, albeit the outcomes for 18 pits is shockingly better in contrast with the one for 19 pits (allude to figure 27). Both execution pointers affirm that the main advantages are accomplished for various 17 and 18 pits.

As shown in subsections 5.1.3 and 5.2.3, the queues additionally reduce with the increment on the quantity of mechanical pits. In correlation with the ongoing scenario, adding four mechanical pits can significantly lessen the time in line. The outcomes show a 35-minute reduction for the investigation queues, which can be converted into functional execution enhancements. It is additionally conceivable to notice the reduction in queues of past cycles, for example, the external washing that dropped the typical holding up time from 12 minutes to 6 minutes at 480 minutes of simulation run.

Expanding the quantity of review pits can be expensive to the organization in the event of a potential extension. Because of this explanation, this concentrate likewise recommends the reallocation of resources, which can be viewed as a more affordable other option. This reallocation comprised of subbing the upholstery pits, which had a scheduled use of just 5% for mechanical pits. It was considered that the upholstery administrations could likewise be performed at mechanical pits. Significant gains likewise happened, including a drop from 85% to 74% on the scheduled usage of mechanical pits. There was a reduction in the normal lead-season of the transports that contracted from 219.57 minutes to 203.80.

Concentrating on the limit of the carport together with development conjectures can be helpful to decide the ideal second to build the quantity of resources to stay away from any potential annoyances in the event of extra demands. This sort of study is additionally critical to forestall superfluous ventures that can come full circle in the wasteful usage of the accessible resources. It is likewise vital to make reference to the advantages that this undergrad thesis brought to the organization in a momentary period. During the improvement period of the simulation model, it was recognized that the organization didn't electronically screen a few cycles. For instance, the fuel loading process was constrained by two representatives who were liable for physically filling a structure containing the appearance seasons of the transports as well as how much fuel stacked. Nonetheless, the method was helpless to imprecisions and restricted the course of information gathering. Then, the organization chose to carry out another electronic checking framework in view of calculation sheets to have a superior command over the data, which is fundamental for creating simulation models or some other kind of measurable examination. Another model respects to the organization's support software. This software has a few functionalities, however the approval cycle of administration orders was loose. In other words, the appearance season of the transports was accurately addressed, however the approval of administration orders could consume a large chunk of the day in the wake of completing a review or a support administration, which prompted erroneous assessments of the execution season of both. After certain gatherings and conversations with the data innovation division of the organization, it was concluded that a more exact support the board software was fundamental.

Despite the fact that the created model expected a significant measure of data corresponding to the cycles of the organization, a ton of parts of the framework must be rearranged. The organization viable includes a few potential open doors for simulation inside the upkeep office, for example, working with spare parts, individual simulation modules for the cleaning area, and sold vehicles. It is expected that the execution of the new administration framework can expand the exactness of the information from the accompanying cycles: execution of electrical, refrigeration, bodywork and upholstery administrations; examination times; transport appearance time. It would likewise allow further examination of varieties in demand because of occasional elements. Another opportunities for future work comprises on attempting to appraise the effect of vehicle stream in execution measures. In other words, the framework conduct for various stream rates.

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