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Abstract	The primary aim of this project is to optimise the vehicle wash bay at Hatfield VW through the application of various Industrial Engineering tools and techniques. These include time and motion studies; job task standardisation (PDSA cycle application); and simulation modelling in Arena. Application thereof will lead to an increase in productivity and improve efficiency, ultimately benefiting the company as well as the customer. The company seeks a configuration that will allow for a minimum of 75 vehicles to be processed by the wash bay per day. This configuration will then be presented to the company so that they can adapt their wash bay contract accordingly. The secondary aim of this project is to investigate the parking issue at the facility, and to propose and develop a system that will allow for the monitoring of available parking bays as well as aid in making full usage thereof.
Category	Simulation, Process improvement

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Optimisation of a Vehicle Wash Bay and the Development of a Parking Bay Monitoring System

by

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Study Leader: Prof. Paul Kruger

Submitted in partial fulfilment of the requirements for the degree of

BACHELORS OF INDUSTRIAL ENGINEERING

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Executive Summary

The following report details the completion of a final year project required for a Bachelors Degree in Industrial Engineering at the University of Pretoria.

The project work will be completed at The Hatfield Volkswagen Vehicle Dealership which is located on the corner of Duncan and Schoeman Street in Pretoria. The project is primarily based on analysing and optimising the various wash bay activities and resources at the facility in order to develop a wash bay configuration that will maximise throughput and increase customer satisfaction by ensuring the timely and efficient delivery of vehicles.

Large volumes of vehicles occupy the facility's limited number of parking bays on a daily basis, thereby creating large scale chaos and internal congestion. This will also be investigated and a solution to monitor and control parking bays will be proposed.

This report includes necessities such as an introduction to the problem background, project aim, project scope as well as a literature review that delves into the various factors which have lead to the above mentioned situation at the facility and also identifies and describes various tools and techniques which will be utilised in the quest for a solution. Thereafter a motion study, job task standardisation, time studies and the development of the wash bay simulation model in Arena will follow. The simulation model will then be calibrated to ensure that output is as close to reality as possible, thereafter the necessary sensitivity analysis will be performed which will lead to the discovery of an improved wash bay configuration. The conceptual parking bay monitoring system that was developed will then be explained, after which final conclusions and recommendations will follow.

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1 Introduction and Background

1.1 Company Background

The Hatfield VW dealership opened in Pretoria during 1998 and quickly became one of the leading retailers of Volkswagen new vehicles in South Africa. This family owned business with a strong focus on customer satisfaction has earned itself a reputation for service excellence. It is the only dealership in the country that has achieved membership of Volkswagen South Africa's Club of Excellence for the past eleven years. Membership to this prestigious club is only awarded to dealerships that excel in vehicle sales, customer satisfaction and franchise standards. The facility sells both new and used passenger and commercial vehicles. The vehicle service workshop deals with large volumes of vehicles on a daily basis, yet maintains exceptional degrees of service quality.

1.2 Problem Background

One of Hatfield VW's primary activities is the servicing of customer vehicles. Approximately 60-75 vehicles are scheduled to be serviced each day. During the period of time that a vehicle is booked in at the facility it may be dirtied externally and internally by particles in the air; workers or by fluids and materials used during the service process. A vehicle may under no circumstances be returned to a customer in this state as it will lead to dissatisfaction and ruining of the company's reputation. Each vehicle is therefore given a full valet after its service. Similarly, new and used cars that are sold to customers also need a valet to ensure that they are in an impeccable physical condition upon delivery. However, due to the large volumes of vehicles that may be booked in at the facility for service at a specific point in time, some of the vehicles are washed before they are serviced. The mechanics then place special protective blankets on the vehicles to prevent dirtying them.

To fulfil these valet requirements the facility has its own vehicle wash bay area which consists of two wash bays serviced by a team of workers. Serviced, new and used vehicles enter the wash bay area and queue in one of two queues. Each queue leads to an undercover area in which vehicles are cleaned by a worker operating a high pressure hose. The vehicles are first sprayed off with water and then hand washed by the worker. Thereafter it is again sprayed off and moved away from the undercover area so that other workers can then dry the extremities and vacuum the interior. The vehicles are then parked at the facility until collected by customers (See Figure 1 - Wash Bay Layout and Flow)

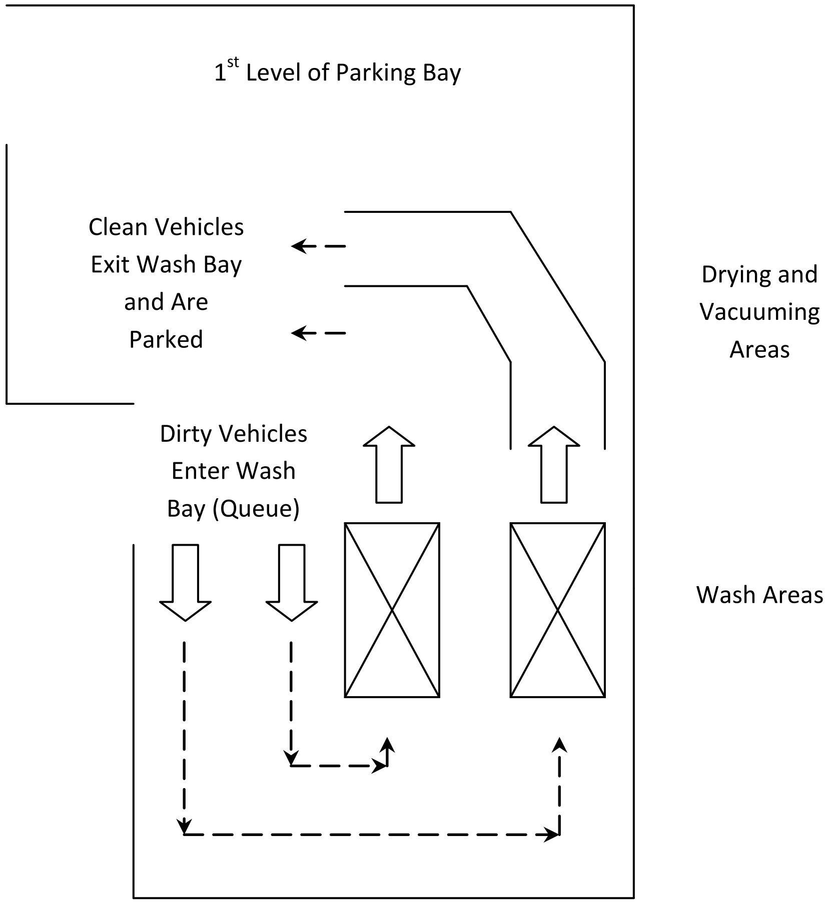

Figure 1 - Wash Bay Layout and Flow

Primary Problem: Seeing as the wash bay forms the final part of the process before vehicles are delivered to customers, it is imperative that the operation flows as efficiently and effectively as possible. At present, Hatfield VW has a contract with an external labour employment agency to provide the team of workers in the wash bay. Due to a lack of proper training and supervision, it is evident through observation that worker idle time is predominant and that workers operate in non systematic ways, therefore hindering the performance of the entire wash bay. At present the wash bay is not capable of completing a full valet on all of the vehicles that it is required to process. At the end of each work day there are a number of vehicles which are still trapped in the system as work in progress, which has a negative impact on the timely delivery of vehicles to customers. Workers that are involved in the drying and vacuuming process are often either waiting for vehicles, or there are no vehicles for them to work on. It is not known whether the current valet process resources (high pressure hoses; vacuum cleaners) are sufficient or optimal, nor what number of workers at each of the various processes would form an optimal wash bay configuration. Standardisation of job tasks and a reconfiguration of the wash bay are necessary to ensure that the required number of vehicles, which will be specified by Hatfield VW, can be completed on a daily basis.

Secondary Problem: The facility has 3 levels of undercover parking, as well as a shade netted area. This parking space is shared between new vehicles that have been delivered from the factory and need to be stored; staff vehicles which are parked during office hours; vehicles that are booked in for only a valet; vehicles that are awaiting service as well as those which have been serviced and washed (Note: vehicles which are either waiting to be serviced, or have been serviced and are waiting to be washed, or have been washed, are called 'workshop cars'). The high demand for parking and the limited space available creates a logistical nightmare. The wash bay is connected to the lowest (1^{st} level) of the parking lot. Upon visiting this section of the facility one senses disorganization and bears witness to vehicles that are parked in ways which obstruct the thoroughfare of the parking lot. At the same time, there are parking bays which are open on other levels of the facility, and could be utilised to alleviate the apparent congestion. Parking space availability changes on a daily basis at the facility and is a factor of the number of vehicles that will be serviced; new vehicles that are delivered from the factory that need to be stored; vehicles that are serviced but need to stay over night; as well as vehicle sales. There is a need for a system to monitor and control parking space at the facility that will allow for the increased utilisation of the parking facility and eliminate the chaos which is present.

2 Project Aim

The primary aim of this project is to optimise the entire vehicle wash bay at Hatfield VW through the application of various Industrial Engineering tools and techniques, including simulation modelling in Arena, so as to increase productivity and improve efficiency, ultimately benefiting the company as well as the customer. The company seeks a configuration that will allow for a minimum of 75 vehicles to be processed by the wash bay per day. This configuration will then be presented to the company so that they can adapt their wash bay contract accordingly.

The secondary aim of this project is to investigate the parking issue at the facility, and to propose and develop a system that will allow for the monitoring of available parking bays as well as aid in making full usage thereof.

3 Project Scope

Regarding the vehicle wash bay:

- A literature review will be conducted in order to identify the root cause of the situation that is present at Hatfield VW (the large volume of vehicles that are entering the facility on a daily basis). It will also be used to explore the relevant Industrial Engineering tools and techniques that have been selected for application throughout this project document. Finally, it will also investigate the effect of adequate supervision on a process

- Motion studies will then be conducted on the wash bay worker processes. The various motions that are recorded will then be studied further to identify any unnecessary motions and illogical sequences of work. Through the application of the PDSA Cycle the job tasks will be standardised
- Time studies will then be conducted on the revised worker processes, and this data will serve as input for the simulation model that will be constructed
- A simulation model will be constructed in Arena, and will be used to replicate reality as closely as possible
- A sensitivity analysis will then be conducted in order to determine an improved wash bay configuration which can then be presented to the company

Regarding the parking area:

- A user friendly system is to be devised to keep track of the number of parking bays available in the facility on a real time basis
- When a system user needs to book a vehicle in that requires parking space at the facility, he/she must be provided with the nearest available parking bay in which the vehicle can be parked (taking into account the various restrictions and assumptions that will be stated)
- The system must allow for vehicles that are parked in the facility to be located with ease

4 Literature Review

4.1 Abstract

This literature review will firstly investigate the project environment so as to provide the reader with an understanding of the problem context. In other words the wash bay process at Hatfield VW will be viewed as forming part of the greater vehicle service process so as to identify how and why the congestion within the wash bay and parking facility has occurred. Secondly this paper will explore, identify and describe the appropriate Engineering methods and tools which will be utilised in the design of a problem solution as well as provide a brief insight into the importance of adequate process supervision.

4.2 Project Environment

A conventional car valet service is comprised of a fixed structure that houses one vehicle at a time and is equipped with a series of motorised high pressure water jets, rollers and high speed air jets. Upon activation of the system water jets spray clean water onto the service of the vehicle to rinse it. Thereafter the water jets spray a mixture of soap and water onto the vehicle, whilst rotating rollers are brought into contact with the vehicles surface in order to wash off any dirt. Once the rinse and wash cycle is complete, air jets blow heated air onto the vehicle in order to dry it. The vehicle will then be driven out of the structure to an area where it can then be vacuumed and the interior components wiped down by a worker.

The above mentioned process is frowned upon by car enthusiasts as the rollers have a tendency to leave very fine scratch marks on the paint surface. This has resulted in a trend towards hand wash car valet services. As the name states, the vehicle is both washed and dried by hand, after which it is still manually vacuumed.

Both of the above mentioned valet methods have one key element in common; they are independent processes consisting of connected functions (wash, dry and vacuum). At Hatfield VW the wash bay/valet forms part of the vehicle service process, making it unique and non-conventional in nature while also exposing it to external factors which have a direct impact on its performance. One of these factors is vehicle sales which will now be discussed further.

4.3 The Economy and Vehicle Sales Trends

In 2009 all the countries of the world faced a bitter reality, the global economic crisis. Closer to home we saw 959 000 job losses, a 70 Billion Rand shortfall in tax revenues and shrinkage in mining and manufacturing sectors due to a loss of exports (Fakir, 2009). The countries Gross Domestic Product (GDP) decreased by 7.4% and 2.8% in the first and second quarters of 2009 respectively which represented the single largest economic slowdown on record for South Africa (Steytler & Powell, 2010). With the fear of wide spread retrenchment looming, and many people already having lost their jobs due to companies becoming insolvent, consumers began spending their money conservatively, resulting in a decrease in vehicle sales. However, growth has since recovered due a recovery in the global economy, and consumers have resorted to lifestyles of the past, spending their well earned money on items that are not considered as being necessary for their survival (Whitlock, 2010). With relevance to this article, car manufacturers have reaped the benefit of this by witnessing a rise in the number of vehicle sales. In 2010, the year after the recession hit, the automotive sector reported strong growth as a whole. New vehicle production increased by 29% and that of vehicle parts and accessories by 22% ultimately reflecting a very important trend, improved and recovered demand (CID, 2011).

NAAMSA – The National Association of Automobile Manufacturers of South Africa is a pre-eminent organisation for all franchise holders marketing vehicles in South Africa. It has membership of major importers and distributors of new vehicles as well as local assemblers and manufacturers. NAAMSA releases monthly new vehicle sales figures which have become recognised as significant barometers of the country's economic activity (NAAMSA, 2011). The figures that are released provide valuable information pertaining to the South African vehicle market with a wide array of graphs and in depth analysis. Figure 2 and 3 show new passenger vehicle sales trends (NAAMSA, New Vehicle Sales Statistics July 2011 (Passenger Cars), 2011).

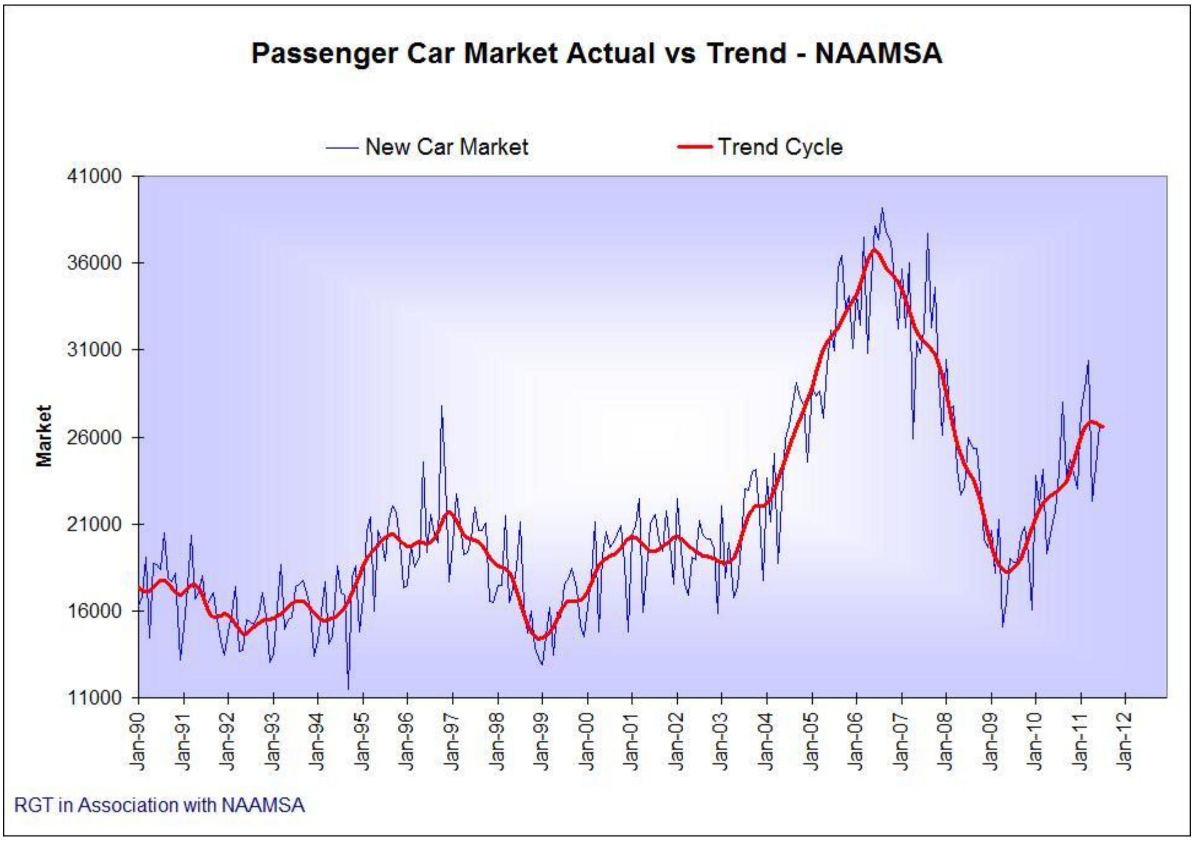

Figure 2 - New Car Market

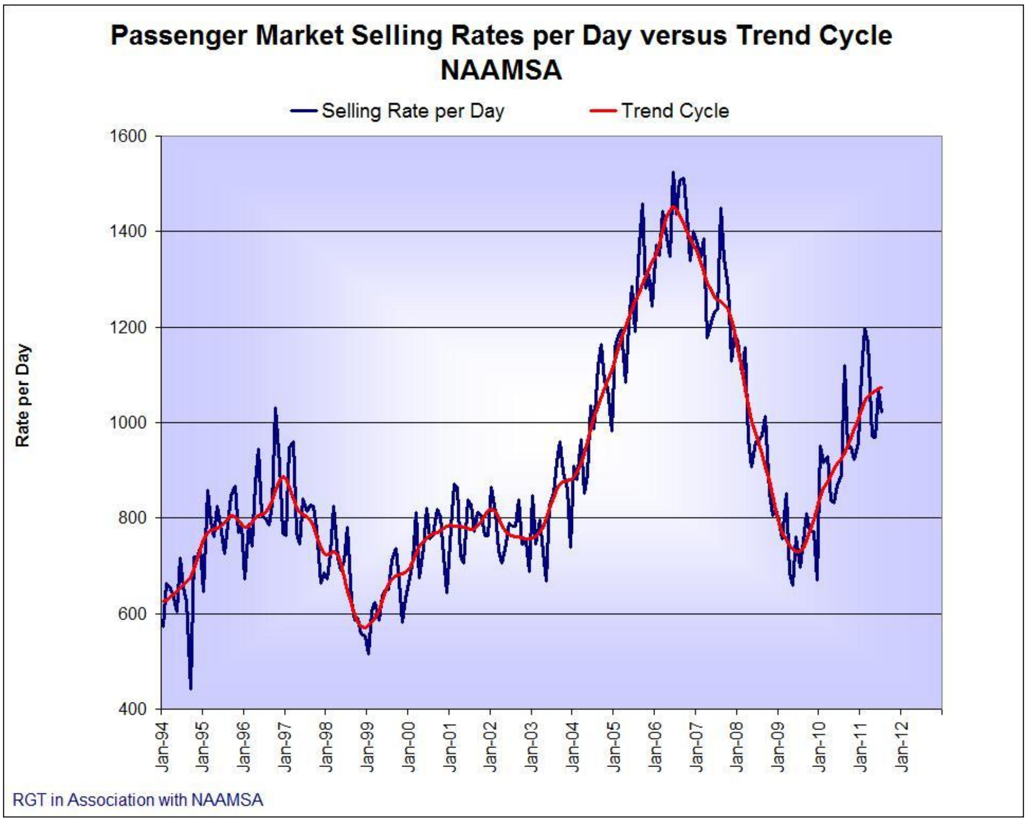

Figure 3 - Daily Passenger Car Sales Rates

The most important aspect to note from the above figures is the increase in passenger vehicle sales since the economic slump of 2009. Although levels do not exceed previous recorded highs in years such as 2005 and 2006 they are much higher than values recorded in the beginning of the millennium, and are on the rise. Figure 4 (NAAMSA, New Vehicle Sales Statistics July 2011 (Passenger Cars), 2011) is an extract from shows the motor industry revenue for the period from 2008 up to 2011.

Motor industry revenue
including VAT
2008 - 2011

	2008 (R million)	2009 (R million)	2010 (R million)	2011 (R million) projected
New cars	84 803	64 565	93 000	108 000

Figure 4 - Motor Industry Revenue

It is once again apparent that the motor industry has made a strong recovery since 2009. The projected revenue for 2011 is not only higher than 2010 and 2011 but 2008 as well. This can be attributed to the fact that vehicle prices are now much higher than they were in 2008. It is possible that growth could continue towards a new all time high. An increase in the number of vehicle sales means that there are more vehicles to be serviced and maintained. Due to rushed lifestyles, and a generation that has turned towards relying on computers and advances in technology to make their lives easier, there are fewer people that work on their own vehicles. Motor vehicle manufacturers have capitalised on this gap in the market and developed well packaged vehicle maintenance and service plans.

4.4 Vehicle Maintenance and Service Plans

According to (Whitlock, 2010) customer service satisfaction in the motor industry is improving however there is still room for improvement. Knowing what customers expect is a critical step in delivering good quality and to ensure customer retention in the long term. Failure to deliver good quality service can be detrimental to the future success of the business due to the complaints, refunds, additional rework and loss of customer base that will occur. Business enterprises continually develop and provide need satisfying solutions to customers for a profit to ensure their economic survival and growth (Gray, 2010) One of these solutions is a vehicle maintenance or service plan.

A motor vehicle service plan aids in retaining a competitive resale value through building a full service history for the vehicle as well as covering all service related costs such as parts and labour, as long as the parts which need to be replaced are not related to general wear and tear. A maintenance plan covers the labour costs of a service and all of the replacement parts that are required including wear and tear items such as windscreen wiper blades, brake pads etc (Volkswagen, 2011). Both types of plans will be limited by either an odometer reading or the age of the vehicle, for example: Volkswagens Premium Automotion Plan is a 5-year/60 000km plan. Therefore all service costs will be covered up until the 60 000km service, and in the event that the vehicle does not reach this odometer reading the plan will expire after a period of 5 years. These plans come as standard on selected models of vehicle, while they can be added to the purchase price of other vehicles to gain the necessary cover. Customers value this feature so much that it has become part of their decision to buy a certain make and model of vehicle. It must be noted that customers are bound to have their vehicles booked for the respective scheduled services before the odometer readings exceed the prescribed service interval values. Contravention of this clause can sometimes result in a maintenance plan becoming null and void.

The development of these products and the ever increasing customer reliance on vehicle franchises to maintain their vehicles has resulted in a dramatic increase in the volume of vehicles that these service facilities have to accommodate and process. As a result more vehicles need to be serviced on a daily basis meaning that more vehicles need to be valeted before customer delivery and that the number of vehicles needing to be housed at a facility is constantly on the rise. The above mentioned findings have therefore established the root cause of the congestion in both the vehicle wash bay and parking area at Hatfield VW.

4.5 Wash Bay Uniqueness and Solution Constraints

In order to improve wash bay performance and ultimately develop an optimised wash bay configuration it would be logical to deduce that reviewing the manner in which vehicles are fed into the process is a must. Due to the fact that the wash bay forms part of the vehicle service and delivery processes it is viewed by the company is a non-primary process, while the physical servicing of vehicles is viewed as a primary process. The company has stated that it would not be feasible to revise service processes in order to accommodate the wash bay when seeking performance improvements.

These complexities have resulted in the need to improve wash bay performance through the application of existing well developed and successful process improvement methods. It was decided upon to construct a simulation model of the entire wash bay and thereby test various configurations until the desired level of output was reached. However, simulation modelling is a later step in the quest for process improvement. The process improvement methods of time and motion studies as well as work standardisation precede it.

This paper will now identify and describe the applicable process performance improvement techniques that can be applied in the optimisation and reconfiguration of the wash bay at Hatfield VW. In addition, the effects of implementing adequate supervision to a process will be explored in order to determine the potential gains of such an action.

4.6 Time and Motion Studies

Important input data for a simulation model is the time taken to perform the various tasks involved. While measuring the times of the various elements of a job one can study worker motions in order to simultaneous develop improved job methods. According to (Sabusinghe, 2009) a time and motion study;

Can be **defined** as:

- The measurement and analysis of the motions or steps involved in a particular task and the time taken to complete each one
- An analysis of the motions used in an industrial process with an aim of improving efficiency and productivity
- A method to establish the best way to perform a task

Has the core **purpose** of:

- Identifying the best sequence in which work should be performed so as to eliminate unnecessary motions thereby maximising efficiency and productivity
- Leading to the standardisation of work processes

(Johnston, 2011) States that the purpose of this type of study is to end "goofing off" through the elimination of unnecessary motions by the worker and to establish what constitutes a fair day's work. This then aids organisational planning by providing a basis for predicting various output levels.

A document published by The University of Washington broke the time and motion study process into three core phases, namely: Measure, Control and Improve. Measure: Involved conducting time and motion studies; Control: Was concerned with the development of standardised work processes; while the Improve phase: Emphasised the establishment of a process of continuous improvement (Washington, 2006)

The list below includes a more in depth description of the steps that comprise a time and motion study:

- Establish the standard job method
- Study the job and break it down into its various elements
- Take time measurements of each job element
- Compute the average time for each job

For ease of measurement any operation should be broken down into groups of motions which are known as elements. The end of one element is known as a breakpoint which is often associated with a sound such as a drill breaking through the part that was drilled or a finished piece hitting a container (Niebel & Freivalds, 2004). Breakpoints in the wash bay will be events such as the moving of a bucket of soapy water, a vacuum cleaning machine being switched off or a worker lifting his drying rag off of the surface of the vehicle to begin drying another body panel.

(Niebel & Freivalds, 2004) State that one of two time study techniques can be utilised. The *continuous timing* method allows the stopwatch to run for the entire duration of the study. The analyst records the time on the stopwatch at the breakpoint of each element while the time is allowed to continue. The *snapback* method involves resetting the stopwatch to zero after recording the time at the breakpoint of each element. The next element is then measured with time which increments from zero.

Through conducting a time and motion study unnecessary motions and illogical orders of operation will be identified. In order for an attempt at process improvement to be successful, it is important to bring order to a chaotic activity through standardisation of the respective job processes. A proven and highly successful manner of achieving this is through the application of the SDSA (Standardise, Do, Study, Act) cycle and the PDSA (Plan, Do, Study, Act) Cycle. These will now be discussed further.

4.7.1 The SDSA Cycle

The Standardise, Do, Study, Act (SDSA) cycle is a technique that helps employees standardise a process. (Gitlow, Oppenheim, Oppenheim, & Levine, 2005) Defined the four steps of the cycle as follows:

- *Standardise*: Where employees study the process and develop best practice methods. All employees doing a job need to agree on a best practice method, for if multiple employees perform the same job in different ways it will result in increased process variation, ultimately affecting the customer negatively
- *Do*: In this stage employees conduct experiments using the best practice methods on a trial basis
- *Study*: Employees collect and analyse data from the trials that are conducted in the Do stage in order to determine the effectiveness of the best practice methods
- *Act*: In this stage managers establish standardised best practice methods and formalise them through training

Once best practice methods have been developed through application of the SDSA Cycle, one can apply the PDSA Cycle in order to further improve the best practice methods.

4.7.2 The PDSA Cycle

The Plan, Do, Study, Act cycle (also referred to as the Deming cycle) can aid management with the improvement of an existing process and is aimed at narrowing the difference between process performance and customer needs and wants (Gitlow, Oppenheim, Oppenheim, & Levine, 2005). The process may already have been redefined using the SDSA cycle, but can then be revised and further developed using the PDSA cycle. Below is a description of the various stages of this process improvement method:

- *Plan*: Involves planning a change that will be implemented to a process under study. This will generally involve a change to the order or manner of performing various tasks
- *Do*: Experiments are conducted to determine the effectiveness of the plan
- *Study*: Is aimed at determining if the plan has been effective in reducing the difference between process performance and customer expectations
- *Act*: The plan is integrated into the process

Through proper application of both the SDSA and PDSA cycle order will be brought to a previously chaotic process and not only will the processes performance increase but it will also become predicable. This will then allow for further and more advanced process performance techniques to be applied, one of these being simulation modelling.

4.8 Simulation Modelling

A simulation can be defined as the imitation of some real device or state of affairs which attempts to represent certain features of the behaviour of a physical or abstract system by the behaviour of another system, namely the process of model execution (CEENEX, 2005).

Simulation modelling forces one to think in global terms about system behaviour, and about the fact that systems are more than just the sum of their components. It provides valuable insight into the designs of production lines and processes before a large amount of capital investment takes place. Traditionally operational experience is the key tool utilised in process improvement, however this can be risky due to premature expenditures without the guarantee of results. Simulation can provide valuable insight into process performance before any changes are implemented in reality. This insight aids the process designer to pre-test various configurations, assess alternatives and to show that a specific process configuration performs in a manner that meets expectations (Kirby & Sawhney, 1997).

Research conducted by (Kellner, Madachy, & Raffo, 1999) found six main categories of purpose for using simulation modelling, namely:

- Understanding
- Process planning
- Control and operational management
- Strategic management

- Process improvement
- Training of employees and learning

They argue that the main motivation for developing simulation models is that it is an inexpensive platform by which insight into processes can be gained when the risks, costs or logistics of making changes to a real system are financially infeasible.

Changes that are made to a process in a world of virtual reality and then implemented in reality are often worthless unless adequate supervision is provided to ensure that the implementation thereof goes smoothly and that the redefined process is operating as planned. The importance and benefits of process supervision will now be explored.

4.9 Process Supervision

Supervision is an activity that is carried out by a supervisor and entails overseeing the progress and productivity of workers that report directly to the respective supervisor. The core function of a supervisor can be viewed as the assignment of tasks and responsibilities to workers while expecting a certain degree of accuracy and punctuality from the respective parties in the execution thereof (Mills, 1997).

(Dawson, 1926) Described and defined three core functions of supervision as follows:

1) *Administrative:* Promoting and maintaining good standards of work while ensuring the efficient and smooth running of a process
2) *Educational:* Developing the educational level of a worker in a calculated manner so as to allow the worker to improve himself and reach his full and required level of performance
3) *Supportive:* Maintaining good, prosperous relationships between various workers

(Burton, 1930) Explained that supervision has the positive effect of steering a worker in the right direction in the execution of his tasks, all while enabling him to use his own initiative and to take responsibility for his various actions.

It is hereby evident that supervision ensures that a process is performing as required by ensuring that respective workers perform their tasks as required. It also promotes a healthy work environment for all of the parties involved and aids the respective workers in reaching their full operating potential. The application of adequate supervision to a process will therefore be beneficial.

Road Map for the Development of an improved Wash Bay Configuration

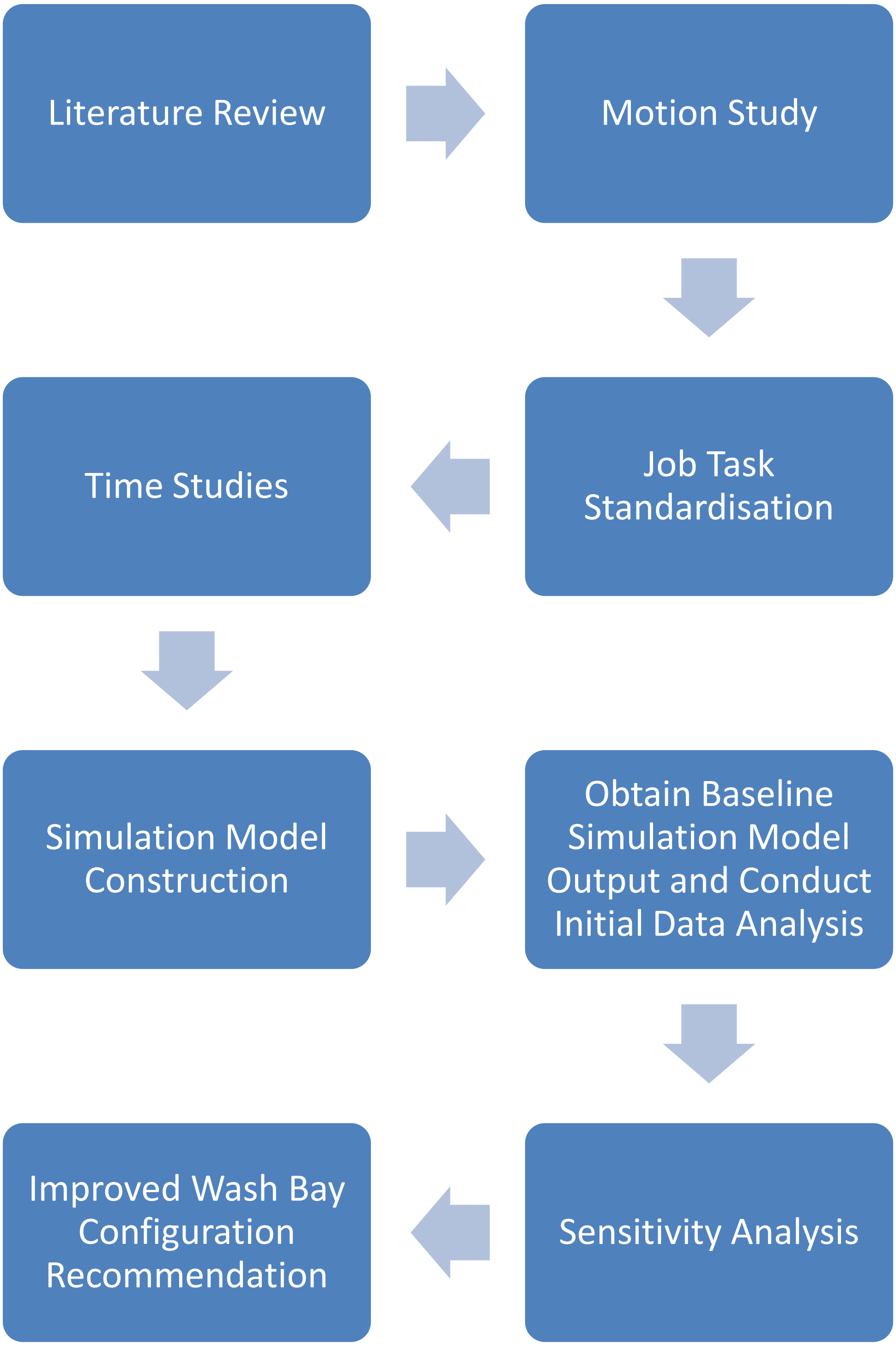

Figure 5 - Road Map Depicting the Processes Involved in the Development of an Improved Wash bay Configuration

5 Motion Study

Upon visiting the wash bay it was apparent that the motions of the various workers were very erratic and inefficient while conducting their duties. The workshop manager agreed that their work methods were not consistent and needed some form of improvement. A motion study was proposed which would analyse the various motions and steps involved in the various the tasks which are conducted in the wash bay. This would ultimately result in the elimination of unnecessary motions and lead to the identification and development of the best sequence of motions for maximum worker efficiency and productivity.

The steps that will be used in the motion study include:

- Establishing the present standard job method
- Breaking down the job into its various core elements
- Studying the job in order to identify unnecessary motions and illogical sequences
- Planning for redefining worker processes

The completion of this motion study will then allow the various wash bay jobs to be standardised by either applying best practice methods or through the development of a smooth and more logical workflow.

5.1 Establishing the Present Job Standard Method

In order to determine the current job methods in the wash bay, some form of evaluation had to be conducted. The best possible way to do this was by setting up a form and then recording worker processes through visual inspection. The recorded data could then be studied in order to identify any emerging patterns which would signify the existing job methods.

As can be seen in Appendix A neither the workers that were washing, drying nor vacuuming vehicles applied any clear form of sequence in their work. This could indicate either the absence of standardised work processes at the facility, lack of worker adherence to current policies or inadequate training and supervision. Upon investigation and discussion with various employees it was found that workers were left to perform tasks at their own discretion, and that no form of work standardisation exists.

5.2 Breaking Down Jobs into Their Various Core elements

Washing primarily consists of:

- Rinsing a vehicle to loosen dirt and minimise damage to paint
- Washing of a vehicle by hand using a sponge and shampoo solution
- Rinsing the vehicle to remove the shampoo solution and dirt

Drying primarily consists of:

- Using a drying cloth to dry the exterior of the vehicle
- Drying the inner metal regions of the doors, bonnet, boot/hatch
- Wiping the interior regions of the vehicle (door panels, dashboard)

Vacuuming primarily consists of:

- Using a vacuum cleaner to eradicate dust and particles from the upholstery

5.3 Identification of Unnecessary Motions and Illogical Sequences

Washing

The wash process contains no apparent logical flow structure (Appendix A) and the workers regularly switch between two vehicles for no apparent reason often returning to wash a completely different region of the vehicle that they initially abandoned. The wash process is in urgent need of a standardised process which will not only stabilise the task but make it easier for the worker to complete.

Drying

As with the wash process there was very little structure present. Workers would often dry an area (such as a door) and then proceed to dry another region (such as the roof) which will end up rewetting a region that was already dried (Appendix A). This rework and lack of a process to follow indicates an urgent need for process standardisation. Of greater concern, is the fact that workers also do not tend to finish the job of drying one vehicle and then proceeding to the next.

Vacuuming

The workers involved with the vacuum process also work very sporadically, seemingly adding unnecessary and unproductive effort to their tasks through the illogical execution thereof (Appendix A).

5.4 Plan To Redefine Worker Processes

Each of the wash bay jobs needs to be reviewed and redefined in order to minimise the apparent inefficiencies. This will be achieved through the standardisation of the various jobs processes, and the retraining of workers on how they should perform there tasks. Standardising these processes will be achieved through the application of the PDSA cycle.

6 Job Task Standardisation

Upon conducting the motion study in the wash bay, it was apparent that the workers had no clear set of standard procedures to follow when conducting their work. Tasks were performed with very little consistency, and sometimes the sequence in which workers completed their interrelated tasks actually caused bottlenecks and induced worker idle time. The first step in the optimisation of the wash bay will be to standardise the various worker processes and tasks that need to be performed. This will be achieved by applying the PDSA (Plan, Do, Study, Act) cycle in order to determine the new best practice method and to ensure that the new methods of operation are embedded in the various activities. This needs to be done so that time studies can later be conducted which will provide input data for the construction of a simulation model.

6.1 PDSA Cycle Application

This business improvement methodology consists of four distinct stages; each will be described and applied systematically in order to achieve consistency and control within the various wash bay processes. This cycle is primarily concerned with planning a change; implementation thereof; checking that the activities are being performed as planned and then acting on any problems that have appeared which are resulting in deviation from the plan.

6.1.1 Plan

During this phase the current set of operations will be investigated and potential solutions to problems discovered will be proposed.

Aim Statement: The overall objective is to eliminate the current chaos and inconsistency in the wash bay by standardising the various worker tasks and thereby bringing about a consistent level of performance that will be delivered by workers and unlock future improvement potential within the facility. The steps to achieve this involve:

- Describing the wash bay activities at present as well as identifying any existing problems
- Describing possible causes of wash bay process variation
- Defining the ideal flow of entities through the wash bay
- Preparing redefined job descriptions for the target population (Improvement theory)
- Defining a list of authorities to establish who can/must do what
- Giving consideration as to how the new processes will be communicated to the workers
- Establishing a time frame for implementing the plan
- Define a measurable improvement objective
- Generating an idea for possible process quality control

6.1.1.1 Description of Present Wash Bay Activities And Identified Problems

A) *Vehicle Washing*
There are two workers (one per queue) that perform the task of washing vehicles. Motion studies showed little to no consistency in the execution of their duties. For example, a worker would often start the process by washing the roof of one car, while other times he would start off by washing the bonnet or one of the sides of another. More disturbing was the fact that often a worker would be washing a specific car and without completing the wash process he would begin washing another car, and than sporadically return to the car he was busy with initially. The lack of consistency within this job needs to be addressed.

B) *Vehicle Drying*
It was found that on average two workers will simultaneously dry a vehicle (per queue). Once again their processes were not consistent. Sometimes a worker would just disappear to the rest room, or a third worker would appear and aid the two workers who were busy drying the vehicle. These issues need to be addressed and a more structured approach to performing this job needs to be developed.

C) *Vacuuming of Vehicles*
Two workers were present to vacuum vehicles at the facility (one per queue). Neither of these workers executed their duties with consistency, often cleaning the interior of the vehicle with extremely irregular, inefficient and illogical patterns.

D) *Moving of Vehicles*
Each queue had one worker to move its vehicles. Little fault can be found with their methods of work, however they were often not very observant as to what was going on in the various parts of the wash bay.

6.1.1.2 Possible Causes of Wash bay Variation

Two apparent root causes of the above mentioned variations and worker inconsistency are:

- Lack of structured work processes
- Lack of proper training
- The absence of adequate supervision

6.1.1.3 Ideal Flow of Entities Through the Wash Bay

Ideally, vehicles should be washed, dried and then vacuumed following a first come first serve (FIFO) basis. Exception may only be made to this rule if a vehicle is given urgent delivery status (For example: A customer that will be collecting their new or serviced car at an agreed time), whereby a vehicle may jump the queue. Due to space constraints at the facility as well as the large volume of vehicles which are present at any time in the wash bay, it is impossible for the other vehicles to be moved out of the way in the queue. There is however space available in front of the left hand side wash area where a vehicle can be slotted into the process. When this situation occurs, vehicles must first be cleared from the drying and vacuuming area after which the specific vehicle can enter the wash bay. (See Figure 6 - Wash Bay Layout and Flow (Depicting the Situation When a Vehicle Jumps the Queue)

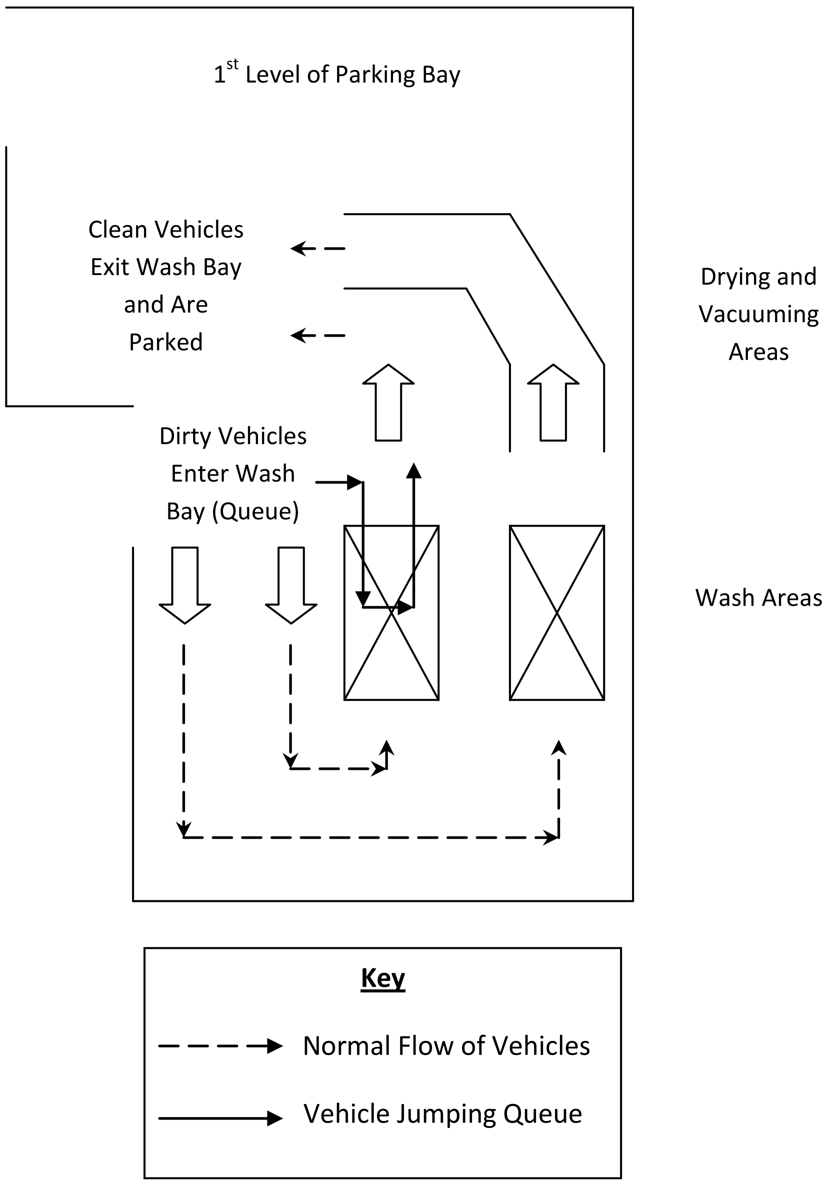

Figure 6 - Wash Bay Layout and Flow (Depicting the Situation When a Vehicle Jumps the Queue)

6.1.1.4 Redefined Job Descriptions of Target Population (Improvement Theory)

Following the research conducted and reviewed in the literature study, the various jobs in the wash bay will have their revised methods developed below. This information will also form the content for a training manual.

A) *Vehicle Washing*

This task will be performed by a single worker per vehicle

- Spray vehicle off with water via the high pressure hose. This will loosen surface dirt
- Prepare a bucket with a car wash shampoo (If some remains from a previous car that was washed it may be reused, as long as the solution does not contain to many impurities and sand particles which may damage paint)
- Using a sponge start washing the roof and windscreen of the vehicle followed by the left hand side, proceeding in an anticlockwise direction to do the rear end; right hand side and lastly the bonnet. All of the doors as well as the boot lid/hatch and bonnet must be opened to reveal hidden parts of the body so that these areas can be cleaned.
- Using the dirtied bucket of water, the wheels must now be cleaned

B) *Vehicle Drying*

Two workers will jointly dry a vehicle

- The roof and windscreen of the vehicle will be divided into two sections. Each worker will simultaneously dry their half of the roof area
- Which ever worker finishes drying their roof section first will proceed to dry the bonnet, under the bonnet and then the front mudguards. The slower worker will then proceed to dry the rear end of the vehicle (rear window/boot lid/hatch) as well as inside the boot lid/hatch
- Each worker will then return to the side corresponding to the area of roof which they dried earlier and proceed to dry both the exterior and interior regions of the doors. While drying the interior region of the front door, a worker is responsible for wiping their corresponding area of dashboard inside the vehicle
- While drying the interior regions of doors/boot lids/hatches workers must also wipe down the door panel/door handle area to ensure ultimate cleanliness
- The worker that completes their task of drying first is then responsible for applying tire polish to each of the tyres while the second worker then proceeds to dry the vehicle

C) <u>Vacuuming of Vehicles</u>

This task will be performed by a single worker per vehicle

- A worker will start by vacuuming the right front (drivers) section of the vehicle. Thereafter the worker will proceed to vacuum the vehicle in a clockwise direction by continuing with the right rear, boot, left rear and then the left front area

D) <u>Moving of Vehicles</u>

As depicted in Figure 5 there are two queues in the wash bay. There will be one worker assigned to move the vehicles in each queue

- Vehicles are mostly delivered to the queue by mechanics (if entering via the workshop) or can be collected from the parking bay by one of the two employees in the wash bay
- It is the workers responsibility to ensure that the wash, drying and vacuuming areas are always occupied with vehicles and not idle due to a lack thereof

6.1.1.5 List of Authorities

- Only a wash area worker may operate a high pressure hose and wash the vehicles
- Only workers who are hired to dry the vehicles may do so
- Only workers who are assigned to vacuuming vehicles may do so
- Due to insurance and liability concerns, only the two workers assigned to moving vehicles in the wash bay may do so
- Workers may not lend their equipment to other workers, the responsibility is their own to safeguard the equipment assigned to them
- If a worker is absent it is the responsibility of the contractor to ensure replacement labour

6.1.1.6 Communication of Plan

- Seeing as the wash bay workers are externally contracted via a subcontractor, the redefined job descriptions will be discussed with their employer
- It must be made clear that the workers tasks actually remain the same, it is just the order in which work is conducted that is redefined in order to achieve consistency and control, which will unlock improvement potential
- It will then be the subcontractors responsibility to communicate these revised job descriptions to his workers

6.1.1.7 Time Frame

One week of on the job training and active supervision from the subcontractor as well periodically from the workshop manager will be required for the implementation of this plan

6.1.1.8 Measurable Improvement Objective

The primary desired outcome of this exercise is to standardise the various worker processes within the wash bay and thereby achieve greater consistency and performance. However, this can all be done in theory but means nothing unless successfully implemented in practice. Means of measuring the success of thereof will be done by visual inspection in order to observe the ease of worker adaptation and compliance to the redefined job descriptions. It is important to determine the workers perceived satisfaction attained from the new work methods. Short discussions must be held with each worker so that their thoughts and opinions can be voiced. Positive feedback in this regard, as well as worker compliance to designated work methods will display that the objective of standardisation has been successfully met.

6.1.1.9 Ensuring Quality

- Key to the success of the recommended changes is supervision. The absence of adequate levels thereof could lead to workers deviating drastically from the norm and impacting the negatively on wash bay performance
- It is suggested that workers should be observed after retraining and implementation in order to identify individuals who are involved in the process that may possess potential for bearing the responsibility of supervising others. This worker will then keep an eye on wash bay proceedings and ensure worker commitment, minimise the amount of worker induced idle time and aid to the overall optimal functioning of the wash bay

6.2 Do

This stage of the cycle involves putting the plan into action and will involve:

- Retraining of workers in accordance with the revised job descriptions
- Supervision by the contractor to ensure that the workers have understood their instructions and are working accordingly
- Ensuring that the relevant documents and procedures are available where necessary. Due to the potential illiteracy of workers, pictorial descriptions of their work flow must be made available
- Emphasis must not only be placed on how the workers are working, it must also be ensured that the workers have the relevant resources at their disposal to conduct their tasks (Sponges; shampoo etc)
- The workshop manager must also step in and observe the activities in the wash bay periodically to ensure that the subcontractor is performing as required

6.3 Study

This stage of the cycle involves process verification to ensure that the desired results have been achieved. This will primarily be done through visual inspection. Any deviations from the plan should be noted. This should be the responsibility of the subcontractor, but it is necessary that the workshop manager gets involved.

6.4 Act

If the “Study” phase noted any discrepancies between the plan and what is done we will need to determine the relevant causes and take appropriate action to rectify the situation. Use will be made of 3 main types of improvement action:

- Steps to fix the immediate problem
- Corrective action to eliminate the causes of nonconformity
- Preventative action to prevent the causes of potential non-conformance

7 Time Studies

The various wash bay processes have been standardised and therefore stabilised. With a more predictable array of processes in the wash bay we can begin preparation for the later development of a simulation model. However, input data for the simulation is required in the form of:

- An account of the present wash bay resources
- Time values for the various activities performed in the wash bay

Visual inspection, consultation with workers and time studies (using the continuous timing method as identified in the literature review) will be utilised in the gathering of the above mentioned data.

7.1 Account of Present Wash Bay Resources

At present, there are:

- 2 workers that wash vehicles (1 per queue)
- 4 workers that dry vehicles (2 per queue)
- 2 Workers that vacuum vehicles (1 per queue)

Each queue has one high pressure hose which is used by the worker that washes the vehicles.

7.2 Time Values of Various Wash Bay Activities

Each of the three wash bay processes (washing; drying and vacuuming) had a stopwatch time study applied to them after which the respective average times were derived in the form of a triangular statistical distribution. Each of the various workers were observed and timed in order to eventually derive average times that included both more and lesser competent workers. Appendix A contains an example of the time study form that was used. Table 1 below contains the calculated average times in minutes that will serve as input data for the simulation model in Arena. Times for drying teams consisting of both one and two workers are included.

Process:	Minimum:	Most Likely Value:	Maximum:
Wash	6.5	8	9.5
Dry (2 workers)	11.5	14	16
Dry (1 worker)	20	25	32
Vacuum	6	9	14

Table 1 - Calculated Average Process Times

8 Simulation Model Construction in Arena

In order to derive an optimised wash bay configuration, it is necessary to first establish a performance baseline which is modelled on reality (present configuration). Once this model is calibrated to ensure that it is providing output which is as close to actual system output as possible, a sensitivity analysis can then be performed to determine the impact of various changes on the system, and ultimately allow us to decide on the changes to be applied in reality so as to improve the overall processes performance.

Before the model can be constructed it is necessary to define some general assumptions which apply to it.

8.1 General Assumptions

- Workers will perform their various tasks as set out in the previous chapter containing standardised work procedures
- Workers work for 8.5 hours per day
- Workers in Queue 1 have an hour lunch break from 12:00-13:00
- Workers in Queue 2 have an hour lunch break from 13:00-14:00
- There are 9.5 hours in a work day at the facility
- The final 30 minutes of the work day sees no arrivals from the workshop
- Average process times as established in the time study will be utilised as input data
- Due to space constraints, no more than 3 vehicles may be present in the wash area at any point in time
- Due to space constraints, no more than 7 vehicles may be present in the combined drying and vacuuming area at any point in time
- General logical process flow is wash, dry then vacuum. However, if a worker that must vacuum a vehicle is first expected to wait for it to be dried, large scale congestion will be caused in the drying and vacuuming area due to the fact that there is only space for 7 vehicles. It was agreed that if there are 5 vehicles waiting to be dried at a point in time, then the worker operating the vacuum cleaner may vacuum cars which then enter the queue after which these vehicles will wait to be dried
- Vehicles arriving at the wash bay will tend to be added to the shortest queue, however, queues do not need to be equivalent lengths
- For the sake of the simulation model similar arrival rates will be utilised for each queue
- It is not assumed that the output from both queues will be the same (different work rates; lunch break times etc). It is common that one queue out performs another on a daily basis

Seeing as the baseline model will contain the core operating logic of the wash bay functions, and that later models will simply be an adaptation thereof, this section will describe the various components of the constructed Arena simulation model as well as their various functions, purposes and interactions with each other. Simulation output data will then be presented and analysed for use in the sensitivity analysis which will follow.

Figures 6 and 7 are captions of the Arena simulation model in static form.

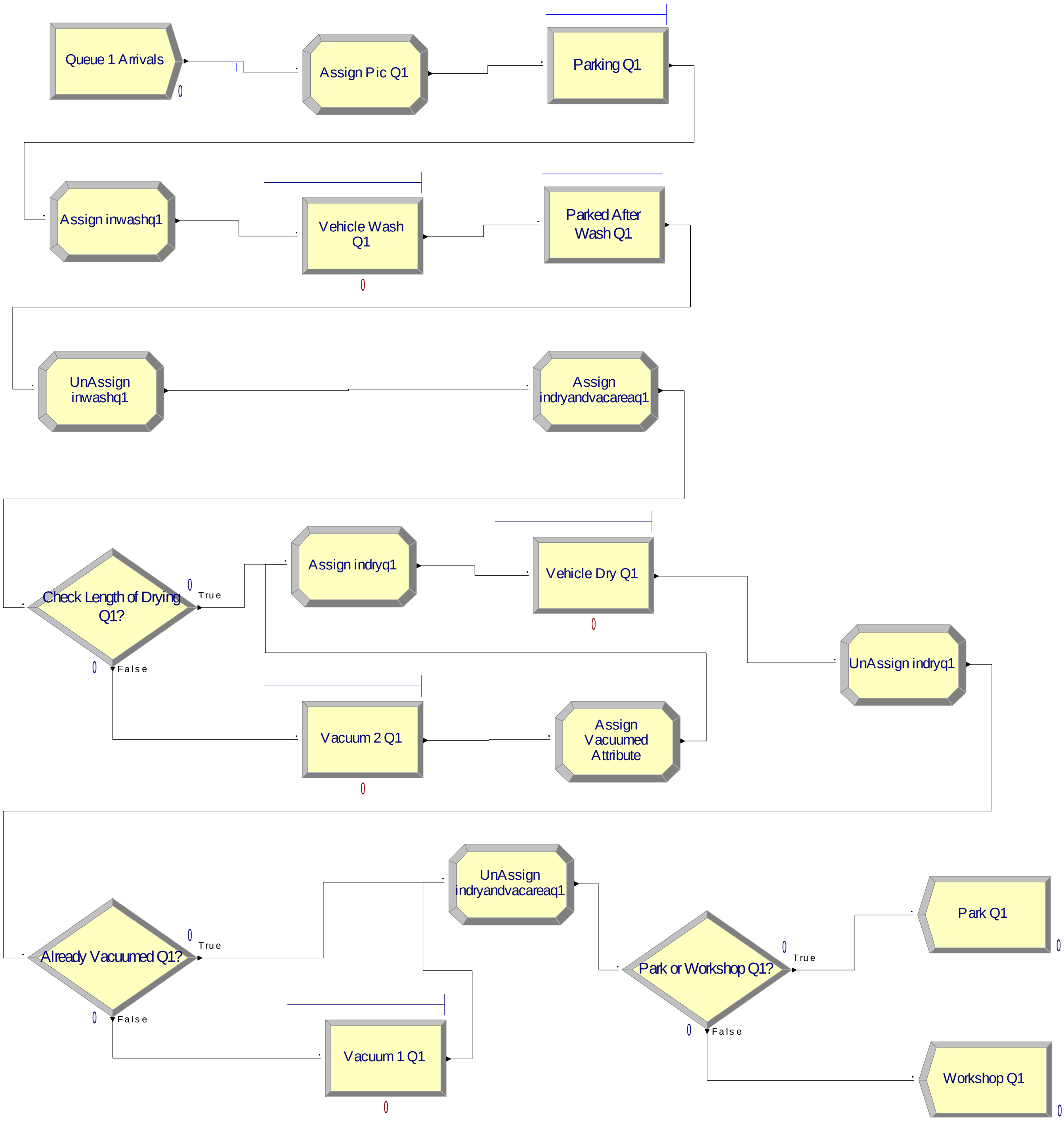

Figure 7 - Simulation Model Screen Shot (Queue 1)

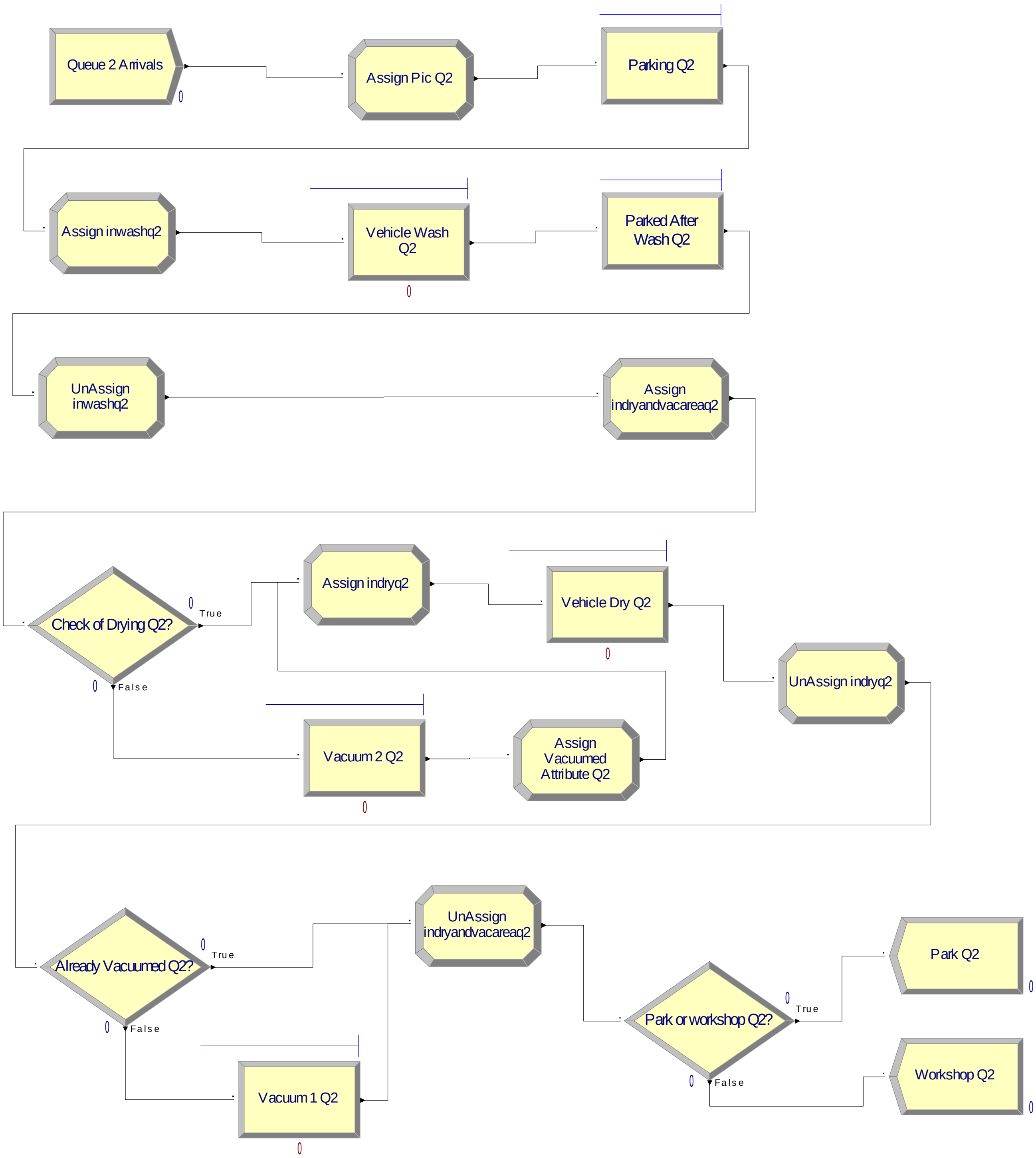

Figure 8 - Simulation Model Screen Shot (Queue 2)

8.2 Model Configuration

The baseline simulation model is based on the present wash bay configuration which consists of 2 queues each containing:

- 1 worker washing
- 2 workers drying
- 1 worker vacuuming

The operating logic of both queues is the same. Queue 1 will be used in the model description below and any differences between the two queues will be highlighted.

8.2.1 Arrivals

Wash bay arrivals gradually increase throughout the morning and then decrease after midday. Queue 1 receives no vehicles between 12:00-13:00 due to the workers being on lunch, while the same occurs in Queue 2 between 13:00-14:00. Figures 8.1 and 8.2 depict the arrival schedule for each queue respectively.

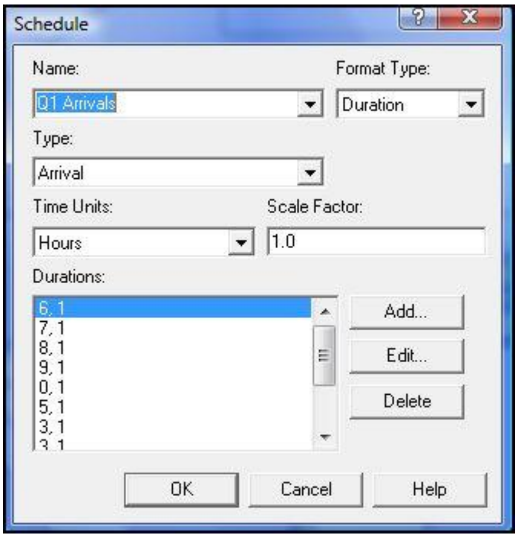

Figure 9.1 - Queue 1 Arrival Schedule

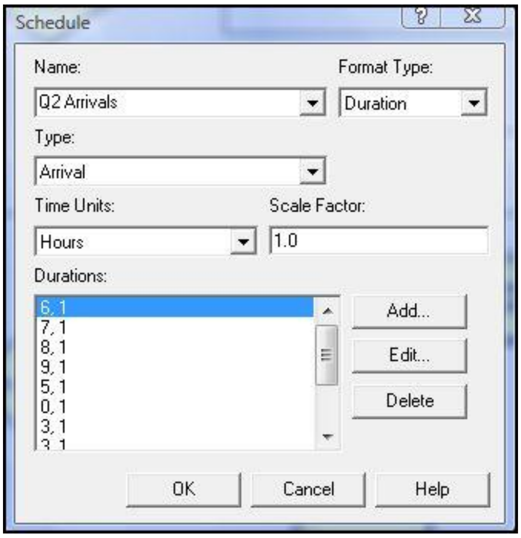

Figure 9.2 - Queue 2 Arrival Schedule

8.2.2 Queue Parking

As mentioned previously, vehicles entering the wash bay area will join one of two queues. The feed of vehicles into the valet system has to be controlled due to space limitations (see general assumptions). The wash area consists of space which allows for one vehicle to be washed, while two others can either wait to be washed or can wait to move to the next process. Two modules are therefore used to simulate the wash area, namely, “Vehicle Wash” and “Parked After Wash”. Even though the module name is “Parked After Wash” provision has been made for the situation where there is 1 vehicle being washed while 2 other vehicles are waiting to be washed. This is however irrelevant, and the most important aspect to note is that there may be no more than 3 vehicles present in the wash area (“Vehicle Wash” and “Parked After Wash” combined) at any point in time.

As can be seen in Figure 9, a “Hold” module was used to simulate the parking space in front of the wash area. This module monitors the variable “inwashq1” which is incremented and decremented via “assign” modules which are located in front and behind of the wash area. To ensure that there are never more than 3 vehicles present, a condition “inwashq1 < = 2” was set up. If there are 2 vehicles in this space, a 3rd will be allowed to enter, after which the rest of the vehicles will wait in the parking queue.

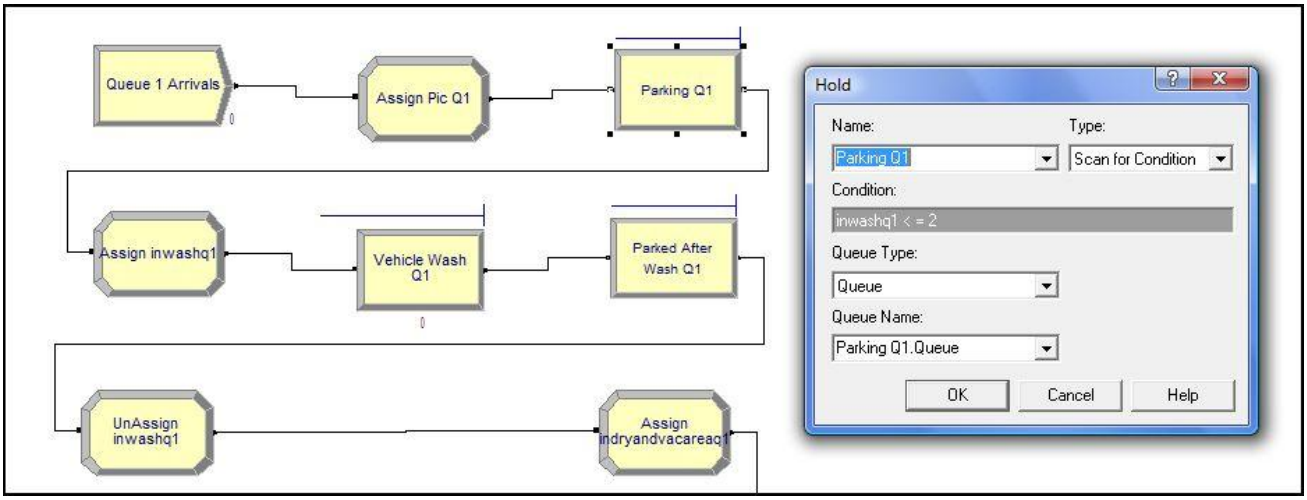

Figure 10 - Hold Module Logic for Parking Area

8.2.3 Parked After Wash

The wash area includes a “Hold” module, which simulates the situation involving vehicles which have been washed and are waiting to proceed to the drying and vacuuming area. This module also makes allowance for the situation where there is one vehicle being washed, while there are two others that are waiting to e washed). However, there is only space available for up to 7 vehicles in the combined drying and vacuuming area. Vehicles therefore cannot be released from the wash area unless there is space available for them further down the process line. To ensure that the model performs accordingly, a variable was created called “inwashanddryareaq1” to keep track of the number of vehicles that are present in the drying and vacuuming area. The wash area “Hold” module (“Parked After Wash”) scans the condition “indryandvacareaq1 < = 6”, and will release a 7th vehicle into that section of the module and hold others until the condition is once again fulfilled. (See Figure 11 - Hold Module Logic to Simulate Wash Area Capacity)

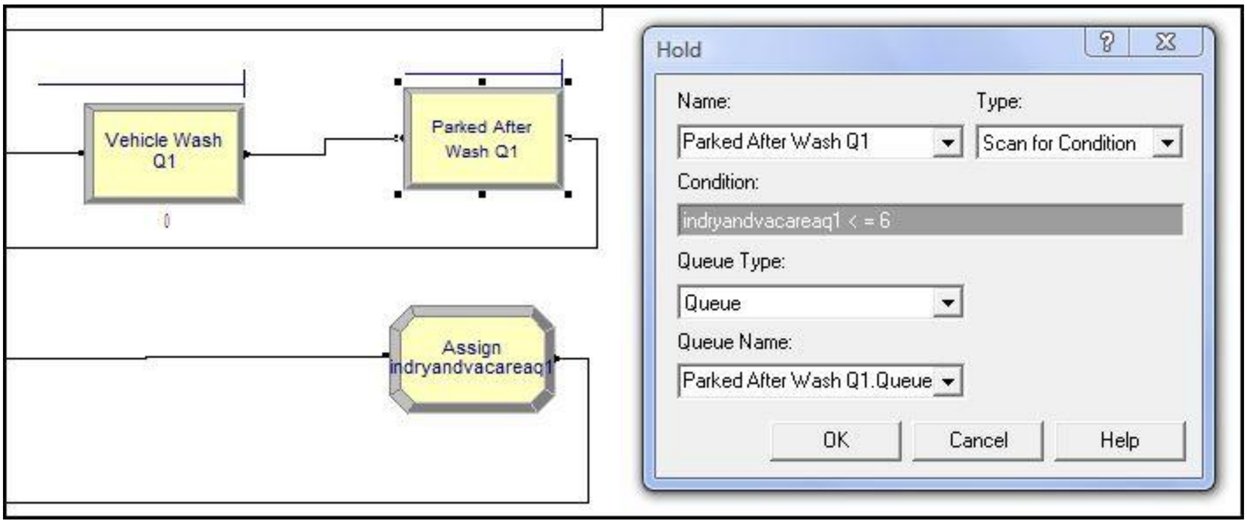

Figure 11 - Hold Module Logic to Simulate Wash Area Capacity

8.2.4 Decision Module to Check Length of Drying Queue

In reality, a worker that vacuums vehicles does not always wait for them to be dried first, as this would amplify congestion within the restricted space of the drying and vacuuming area. A "Decide" module was put into place to monitor the number of vehicles that are waiting to be dried by workers. It was agreed upon that if there are 5 vehicles waiting to be dried, that the 2 other vehicles that will then enter the system will be vacuumed first in order to facilitate the flow of entities. If a number lower than 5 was to be used it would simply congest the drying and vacuuming area as workers that had then been dried would have to wait extremely long to be vacuumed. Figure 12 displays how the model will allow a 5th vehicle to queue for drying, while the 6th and 7th vehicles will then be sent to for vacuuming.

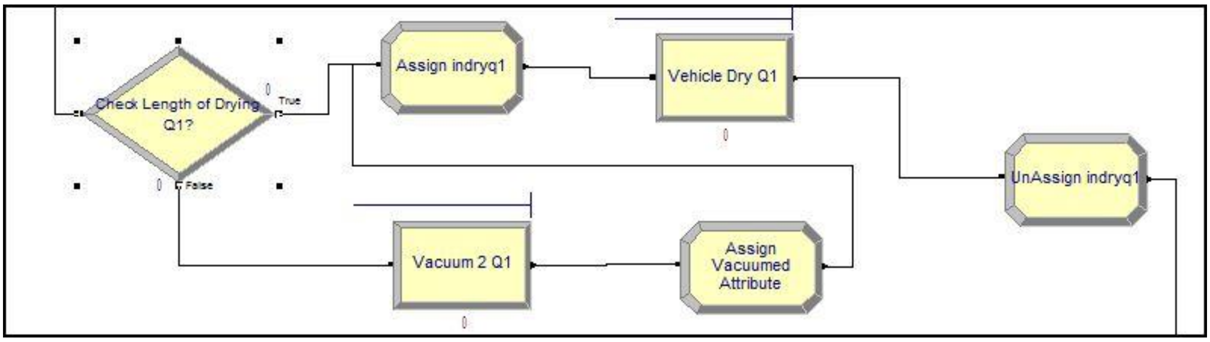

Figure 12 - Simulation Model Screen Shot Depicting the Module under Discussion

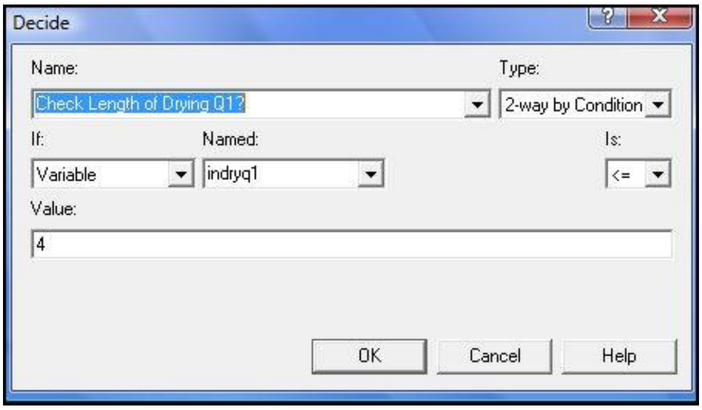

Figure 13 - Drying and Vacuuming Area Operating Logic

It must be noted that the "Vacuum 2 Q1" module seen in Figure 11 (previous page) seizes the same worker as the "Vacuum 1 Q1" module (See Figure 14 - Simulation Model Screen Shot Depicting the Module under Discussion). This module has simply been used to replicate the scenario of vehicles that are being vacuumed first. Vehicles which are vacuumed first then need to wait to be dried, similarly vehicles that have been dried first then need to be vacuumed. Due to the fact that the normal flow of operations is dry and then vacuum, it was necessary to monitor which vehicles had first been vacuumed. An attribute was assigned to these vehicles and a "Decide" module was later used to detect their status (vacuumed or not). Vehicles that had already been vacuumed would then exit the wash bay to either the car park or the workshop, while vehicles that had not would then be vacuumed before exiting. Figure 14 depicts the described process.

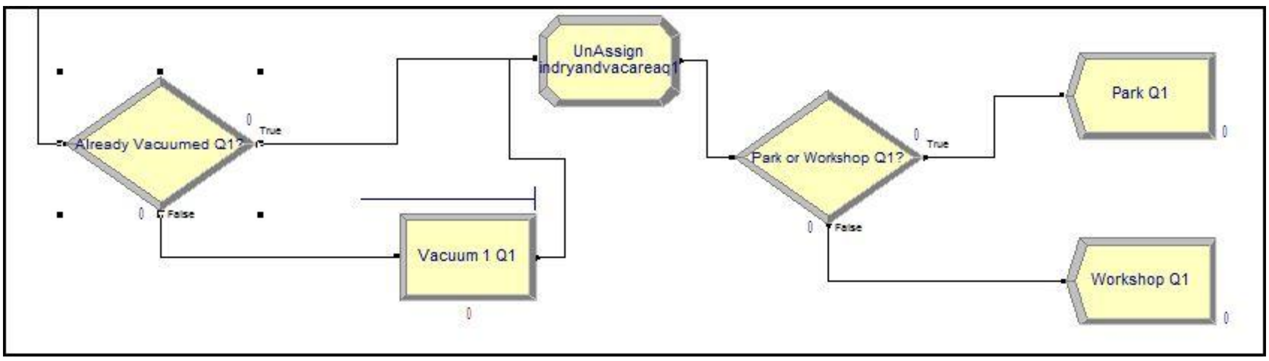

Figure 14 - Simulation Model Screen Shot Depicting the Module under Discussion

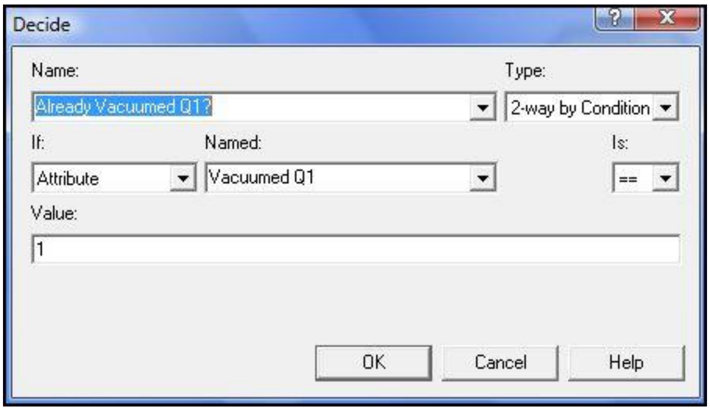

Figure 15 - Decide Module Evaluating Whether Vehicles Have Already Been Vacuumed

9 Baseline Simulation Model Output and initial Data Analysis

This section will provide analysis of certain key output areas of the baseline simulation model in order to ensure that reality has been recreated as accurately as possible and to identify problems that are present within the model. Topics for discussion and calibration certification include the scheduled utilization of the various workers as well as the number of entities that:

- The system receives and then puts out
- Enter and exit the individual wash bay processes
- Are waiting in the various process queues

9.1 System Output

The present wash bay configuration is known to be constrained. Near the end of each work day there are always a few vehicles which are still trapped in the valet process, mainly the drying process, and the respective workers then need to work overtime on top of an already long and physically exhausting day in order to complete them.

The simulation model showed the following:

Entity

Other

Number In	Value
Cars Q1	48.0000
Cars Q2	39.0000

Figure 16 – Baseline Model: Number of Entities Entering System

Number Out	Value
Cars Q1	35.0000
Cars Q2	32.0000

Figure 17 - Baseline Model: Number of Entities Exiting System

System	Average
Number Out	67

Figure 18 – Baseline Model: System Output

Output data coincides with the situation described in the paragraph above; the process is not capable of handling the required number of vehicles per day. The simulation model shows that it is only capable of achieving an average output of 67 vehicles per day (Figure 18 – Baseline

Model: System Output), well below the required minimum average of 75 vehicles. Even though system output is only slightly under the desired amount, it is depicting exactly what is occurring in reality, a process that is not capable of meeting what is required if it. It is now necessary to evaluate which processes are underperforming and causing a bottleneck in the valet process.

It must be noted that we are seeing 87 vehicles entering the system, and 67 exiting. The model is purposely being overfed in order to later ensure that the new configuration is capable of just over the 75 vehicle minimum output. Not all of the 87 vehicles are entering the various wash bay processes; some are remaining in the parking lot. A more accurate way of determining process capability will be to view the number of vehicles that are drawn into the wash process and then compare this to the number exiting the valet system. This will be shown in the following section.

9.2 Entities Entering and Exiting the Individual Wash Bay Processes

We will now look at the number of entities that are entering each individual wash bay process in order to establish which process is not fully capable of performing its function. The following figure contains the relevant simulation output data:

Number In	Value
Vacuum 1 Q1	19.0000
Vacuum 1 Q2	25.0000
Vacuum 2 Q1	23.0000
Vacuum 2 Q2	14.0000
Vehicle Dry Q1	42.0000
Vehicle Dry Q2	39.0000
Vehicle Wash Q1	45.0000
Vehicle Wash Q2	39.0000

Figure 19 – Baseline Model: Number of Entities Entering Individual Processes

Number Out	Value
Vacuum 1 Q1	19.0000
Vacuum 1 Q2	25.0000
Vacuum 2 Q1	23.0000
Vacuum 2 Q2	14.0000
Vehicle Dry Q1	35.0000
Vehicle Dry Q2	32.0000
Vehicle Wash Q1	45.0000
Vehicle Wash Q2	39.0000

Figure 20 - Baseline Model: Number of Entities Exiting Individual Processes

If we have a look at the number of vehicles entering the wash process in Queue 1 and Queue 2, we find that 84 vehicles are in fact being drawn into the system. The problem is that only 67 of them are being processed completely. The other vehicles are either still being cleaned, waiting to be attended to or simply trapped in the system due to congestion.

The ideal situation would be where we have an average of at least 75 vehicles that are being drawn into the valet process and 75 vehicles that exit. This would be a perfect scenario, and some form of leeway needs to be granted. Upon consultation with the company it was agreed that it will be acceptable if a quantity of between 75 and 85 vehicles are entering the system and at least 75 vehicles are seen exiting the system, as the 12% difference between input and output can be left to be managed by personnel involved in the process. The overall aim is to achieve wash bay output of at least 75 vehicles.

Queue 2 is drawing in a substantially lower number of vehicles than Queue 1. Upon investigation it was concluded that this is due to a less efficient team of workers as well as the fact that the two queues are operating on different schedules.

As highlighted in the Figure 18 and Figure 19 the vehicle drying process in Queue 1 has 42 vehicles entering, while only 35 are exiting. Queue 2 has 39 vehicles entering the drying process, while only 32 are exiting. This could be attributed to congestion caused by vehicles waiting to be vacuumed, or it could be due to an insufficient number of workers in the respective drying processes. We will now have a look at the scheduled worker utilisation as well as the average number of vehicles waiting in queues at each process in order to establish a possible cause of this problem.

9.3 Scheduled Worker Utilisation

Figure 20 and Figure 21 below show the scheduled utilisation of workers in the wash bay.

Scheduled Utilization	Value
Dry Team Q1	0.9960
Dry Team Q2	0.9410
Vacuum Team Q1	0.8652
Vacuum Team Q2	0.7269
Wash Team Q1	0.7059
Wash Team Q2	0.6135

Figure 21 – Baseline Model: Scheduled Utilization of Workers (Percentage)

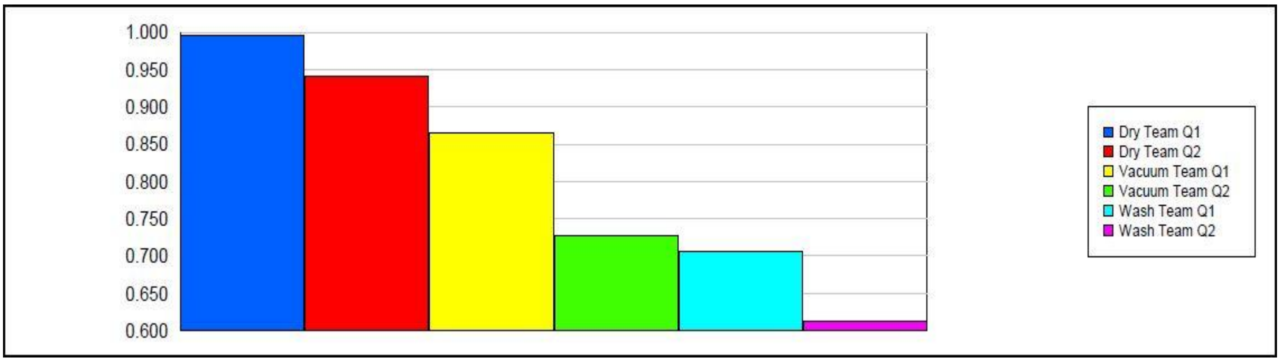

Figure 22 – Baseline Model: Bar Chart Representing the Scheduled Utilization of Workers

Earlier we witnessed that 42 vehicles were entering the drying process in Queue 1 and that only 35 were exiting. In Figure 20 we find that the scheduled utilisation of the vehicle drying team in Queue 1 is 99.60%. This clearly indicates that the drying process is in need of more workers in order to reduce the expectations and stresses placed on the individual workers and so that the efficiency of the entire queue, and the wash bay as a whole, can be increased.

Although immediate concern is being placed on the vehicle drying team the 86.52% utilisation of the vacuum cleaner in Queue 1 means that any adaptations made to increase the output of the drying team could result in the over-utilisation of the vacuum cleaner. This would simply shift the bottleneck to the vacuum process. This will be dealt with in the sensitivity analysis when seeking an optimised wash bay configuration design.

Similarly, concern is raised by the 94.10% utilisation of drying team workers in Queue 2. The vacuum team utilization in Queue 2 is considerably lower than in Queue 1, at 72.69%, which could be attributed to the lower number of vehicles being processed by Queue 2. This utilization percentage could however pose a problem if the drying time size and performance is enhanced.

9.4 Average Number of Vehicles in Queues

Due to the space constraints in the washing as well as the combined drying and vacuuming areas it is vital to ensure that the simulation model is operating accordingly and not allowing more vehicles to enter these spaces than what can be accommodated physically. Figure 22 below shows the average as well as the maximum number of vehicles that are present in each queue in the valet process.

Number Waiting	Average	Half Width	Minimum Value	Maximum Value
Parked After Wash Q1.Queue	1.5646	(Insufficient)	0.00	3.0000
Parked After Wash Q2.Queue	0.7095	(Insufficient)	0.00	3.0000
Parking Q1.Queue	4.7436	(Insufficient)	0.00	14.0000
Parking Q2.Queue	1.0564	(Insufficient)	0.00	6.0000
Vacuum 1 Q1.Queue	0.2801	(Insufficient)	0.00	2.0000
Vacuum 1 Q2.Queue	0.3472	(Insufficient)	0.00	2.0000
Vacuum 2 Q1.Queue	0.2995	(Insufficient)	0.00	1.0000
Vacuum 2 Q2.Queue	0.2424	(Insufficient)	0.00	1.0000
Vehicle Dry Q1.Queue	3.7841	(Insufficient)	0.00	6.0000
Vehicle Dry Q2.Queue	2.5971	(Insufficient)	0.00	6.0000
Vehicle Wash Q1.Queue	0.4262	(Insufficient)	0.00	2.0000
Vehicle Wash Q2.Queue	0.6242	(Insufficient)	0.00	2.0000

Figure 23 – Baseline Model: Number of Entities Waiting in Wash Bay Process Queues

1) Wash Area: As described in the section dealing with the simulation model construction, the wash area consists of space which allows for one vehicle to be washed, while two others can either wait to be washed or can wait to move on to the next process. Model data presented in the figure above shows that the maximum length of the queue of vehicles at the wash process, and that of those that are parked after wash, never exceeds 3 vehicles. All is therefore in order.

2) Drying and Vacuuming Area: There is only space for a maximum of 7 vehicles to be present in this part of the facility at a specific point in time. The data in Figure 22 shows that there are never more than 7 vehicles queuing for either of the processes. If this parameter was exceeded it would show that there was an error with the variable that was used in the simulation model to control this situation.

The data that was presented regarding the number of entities entering and exiting the individual processes in the wash bay, as well as the scheduled worker utilisation points strongly towards the need for an increased team of workers to dry vehicles. It must be noted that this must be done with caution as it could have a detrimental impact on the corresponding wash bay processes.

Due to an increase in the number of vehicle sales there has been an increase in the number of vehicles that need to be serviced, and the demand for vehicle services at motor dealerships is expected to continue to rise further. Hatfield VW therefore seeks to attain an average of no less than 75 vehicles valeted per day. A wash bay configuration that allows for this will be deemed acceptable. As mentioned before it will be tolerated to attain a configuration that has roughly up to a 12% or a 9 vehicle variation between its respective input and output as the company is willing to rely on process management to minimise this margin. This is offcourse only acceptable if at least 75 vehicles are seen exiting the valet process.

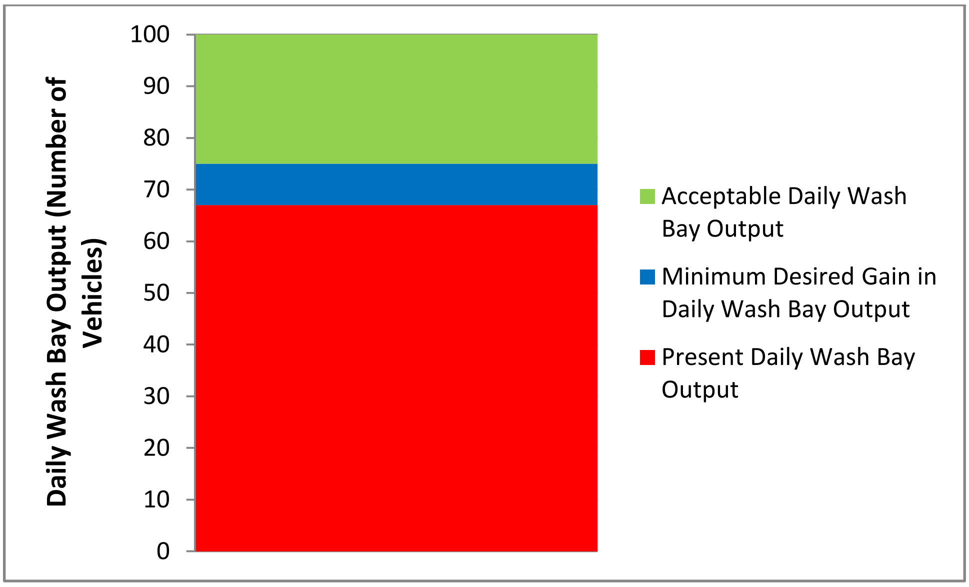

Figure 24 - Desired Daily Wash Bay Output That the Sensitivity Analysis must yield

A sensitivity analysis will now be performed in which various changes to the wash bay configuration will be proposed and the simulation model will be adapted accordingly. The impacts of these changes on overall process performance will be studied and discussed where necessary.

10 Sensitivity Analysis

A sensitivity analysis will be conducted to test the proposed changes and eventually lead to the discovery of an improved wash bay configuration, which yields an output of at least 75 vehicles per day in an effective and efficient manner.

The following list defines the general sensitivity analysis *assumptions* which will be used to guide the optimisation process:

- The number of workers washing and vacuuming vehicles may be evaluated in increments/decrements of one worker
- The number of workers drying vehicles may be evaluated in increments of two. This was decided on by Hatfield VW as the time taken for two workers to dry a vehicle would make it infeasible to employee individual workers, even if they were to assist drying teams of two workers
- Due to the fact that the *simulation baseline model* consists of two workers drying vehicles in each queue, configurations testing the decrease in the number of these workers may be done in decrements of one as a decrement of two workers would result in there being no workers to dry the vehicles. The times for individual workers drying vehicles have not been established (as this process does not occur in reality). For modelling purposes it has been agreed upon that it will be acceptable to double the time that is taken by a team of two workers, and then use this as the new drying process time for one worker

It is necessary to test configurations with resources both above and below that of which the baseline model is comprised. This will be done in a logical manner by first testing a configuration with fewer resources and observing the results, after which configurations with an increased number of resources will be tested. Keeping in mind that the *simulation baseline model configuration* consisted of:

- Queue1: 1 Washer; 2 Dryers; 1 Worker Vacuuming
- Queue2: 1 Washer; 2 Dryers; 1 Worker Vacuuming

The following is a list of configurations that will be tested and evaluated:

<u>Decreased Resource Configurations</u>

<u>Configuration 1:</u>

- Queue1: 1 Washer; 1 Dryer; 1 Worker Vacuuming
- Queue2: 1 Washer; 2 Dryers; 1 Worker Vacuuming

Increased Resource Configurations

Configuration 2:

- Queue1: 1 Washer; 4 Dryers; 1 Worker Vacuuming
- Queue2: 1 Washer; 2 Dryers; 1 Worker Vacuuming

Configuration 3:

With the following two scenarios:

1) Queue 2 Vacuum Team Assisting in Queue 1 When Queue 2 Workers Are In The Idle State

- Queue1: 1 Washer; 4 Dryers; 1 Worker Vacuuming
- Queue2: 1 Washer; 2 Dryers; 1 Worker Vacuuming

2) Employing an Additional Worker to Vacuum Vehicles

- Queue1: 1 Washer; 4 Dryers; 2 Workers Vacuuming
- Queue2: 1 Washer; 2 Dryers; 1 Worker Vacuuming

Configuration 4:

- Queue1: 1 Washer; 4 Dryers; 1 Worker Vacuuming
- Queue2: 1 Washer; 2 Dryers; 1 Worker Vacuuming

While testing the following changes to the facility layout:

1) Increasing the capacity of the wash area from three vehicles to four
2) Increasing the capacity of the drying and vacuuming area from seven vehicles to eight

Selected data from each individual configuration will now be analysed and compared to the *current wash bay configuration*. If a specific configuration yields a favourable result and is deemed to be feasible, it will then serve as a reference for further configuration change testing.

The Arena Simulation Modelling program provides output data under four main headings; which will be used in the discussion of the results. Below is a description of the content that will be covered under each heading:

- *System Output*: Average number of entities that the system processes
- *Entity*: Average value added time per entity; Average waiting time per entity; Number of entities that enter and exit the system

- *Process and Queuing Times*: Average value added time per entity; Average waiting time per entity; Number of entities that enter and exit each individual process. As well as the Average queue waiting times and Average number of entities waiting in various queues
- *Resource:* Scheduled utilization of workers

10.1 Configuration 1

This configuration evaluates the effect of reducing the size of the vehicle drying team in the busier Queue 1 from two workers to one. The resource configuration therefore is as follows:

- Queue1: 1 Washer; 1 Dryer; 1 Worker Vacuuming
- Queue2: 1 Washer; 2 Dryers; 1 Worker Vacuuming

Due to the fact that the primary change has taken place in Queue 1, and the large amounts of output data that have been retrieved from the model, only aspects of Queue 1 will be focussed upon and where relevant those of Queue 2 will be addressed.

10.1.1 System Output

Figure 25 – Configuration 1: System Output

Compared with the data obtained from the baseline simulation model we can see that system output has decreased by 22.39% from 67 vehicles to 52 (Figure 25 – Configuration 1: System Output)

10.1.2 Entity

Table 2 contains the average time that an entity/vehicle which enters the wash bay will spend having value added to it (being valeted) as well as the average time it will spend waiting in Queue 1. The summation of these two times then represents the average total amount of time that a vehicle will spend in the wash bay. The results obtained from Configuration 1 have been tabulated against those of the simulation baseline model results:

Output Area	Baseline Simulation Model (Minutes)	Configuration 1 (Minutes)
Average Value Added Time Queue 1	32.0921	46.4629
Average Waiting Time Queue 1	126.18	172.29
Total Time Spent in Wash Bay	**158.27**	**218.76**

Table 2 – Configuration 1: Average Total Value Added and Waiting Times In Queue 1

We can see that Configuration 1 results in a dramatic increase in the amount of time that vehicles spend waiting in the system, more specifically in Queue 1. This and the increase in the amount of average value added time shows that the reduction in the size of the vehicle drying team in Queue 1 has been detrimental to overall process performance. If one considers that a single 9 hour day is being represented, then the negative effects of such a configuration change will have an enormous impact on the performance and inefficiency of the wash bay as a whole over an extended period of time.

10.1.3 Process and Queuing Times

Table 3 contains select data of the average value added; waiting and total times of vehicles at each process:

Output Area	Baseline Simulation Model (Minutes)	Configuration 1 (Minutes)
Average Value Added Time Per Entity:		
1) Vehicle Dry Q1	13.9873	28.5127
Average Waiting Time Per Entity:		
1) Vacuum 1 Q1	8.4033	2.4762
2) Vacuum 2 Q1	7.4227	3.4923
3) Vehicle Dry Q1	54.4929	127.99
Average Total Time Per Entity:		
1) Vehicle Dry Q1	68.4802	156.51

Table 3 – Average Value Added, Waiting and Total Times of Entities at Individual Processes

The table above shows that the average amount of time that it takes to dry a vehicle in Queue 1 has doubled, and that the time that vehicles spend waiting to be dried in Queue 1 has increased by a dramatic 134.87%. The average total time that a vehicle spends in Queue 1 has therefore increased from 68.4802 minutes to 156.51 minutes; process performance has truly been hindered.

An interesting change in data, which may confuse the untrained mind, is the fact that the average time that vehicles spend waiting to be vacuumed in Queue 1 (either before or after they have been dried) has decreased dramatically. This does not indicate improved performance of the vacuum process; it instead is part of a chain reaction resulting from the reduction in the size of the vehicle drying team. Firstly there are fewer vehicles entering the valet process in Queue 1, and secondly there is greater congestion in Queue 1 itself which has resulted in fewer vehicles entering the vacuum process. This will be confirmed by Figure 24 and Figure 25 which depict the number of vehicles entering and exiting the individual wash bay processes.

Number In	Value
Vacuum 1 Q1	7.0000
Vacuum 1 Q2	19.0000
Vacuum 2 Q1	17.0000
Vacuum 2 Q2	21.0000
Vehicle Dry Q1	24.0000
Vehicle Dry Q2	40.0000
Vehicle Wash Q1	27.0000
Vehicle Wash Q2	40.0000

Figure 26 – Configuration1: Number of Entities Entering Individual Processes

Number Out	Value
Vacuum 1 Q1	7.0000
Vacuum 1 Q2	19.0000
Vacuum 2 Q1	17.0000
Vacuum 2 Q2	21.0000
Vehicle Dry Q1	17.0000
Vehicle Dry Q2	35.0000
Vehicle Wash Q1	27.0000
Vehicle Wash Q2	40.0000

Figure 27 – Configuration 1: Number of Entities Exiting Individual Processes

The *baseline simulation model* yielded a total of 42 vehicles that entered the vacuum process in Queue 1, and all 42 exited. As can be seen in Figure 24 and Figure 25 the vacuum process in Configuration 1 is operating as efficiently as before although there are now only 24 vehicles entering and exiting. The reduction in the number of vehicles entering this part of the valet process is directly related to the increase in the amount of time taken to dry the vehicles, as well as the fact that this congestion is allowing fewer vehicles to enter the valet cycle in Queue 1. (As we can see in Figure 25 only 67 vehicles are now entering the valet system via the wash processes, whereas a total of 83 were found entering in the *baseline simulation model*).

This wash bay configuration has resulted in a few negative aspects regarding the queues of the various processes. Table 4 is a summary of selected average waiting times that were recorded at each of the individual process queues in Queue 1.

Output Area	Baseline Simulation Model (Minutes)	Configuration 1 (Minutes)
Average Waiting Time In Queue:		
1) Parking Q1	83.5156	175.84
2) Parked After Wash Q1	32.5352	67.5145
Average Number Of Vehicles Waiting in Queue		
1) Parking Q1	4.7436	7.9373

Table 4 – Configuration 1: Entity Queue Data at Selected Points in Queue 1

The data in the table above shows that the reduced size and performance of the vehicle drying team is causing large scale congestion in the upstream processes and queues. Firstly, we see that the average amount of time that vehicles are parked after they are washed and are waiting to be dried has more than doubled. Secondly, we see that the average amount of time which vehicles spend queued in the parking space before entering the wash bay processes has also more than doubled.

Inherently, this results in an increase in the average number of vehicles which are queued in these areas. We see that the average number of vehicles which are queued in the parking area before entering the various processes in Queue 1 has increased from roughly five to eight vehicles.

10.1.4 Resource

A valuable indicator and means of verifying potential bottlenecks in a process is the scheduled worker utilization. It has been proven above that this model configuration has resulted in no performance improvement in the wash bay. For the sake of consistency and thoroughness regarding the discussion of results, Table 5 contains data relating to the scheduled utilisation of selected workers in Queue 1.

Output Area	Baseline Simulation Model (Percentage)	Configuration 1 (Percentage)
Scheduled Utilization Of Workers		
1) Dry Team Q1	99.60%	98.43%
2) Wash Team Q1	70.59%	41.35%

Table 5 – Configuration 1: Resource Utilization Data

As we can see, the drying team remains over-utilized while the utilization of the wash team in Queue 1 shows a sharp decline of 29%. This reduction can once again be attributed to the congestion that has been caused in Queue 1 due to the reduced size of the vehicle drying team.

10.1.5 Conclusion

It can therefore be concluded that reducing the number of workers in the two wash bay queues is infeasible and impractical. Therefore, no further wash bay configurations relating to reduced resource capacity will be evaluated.

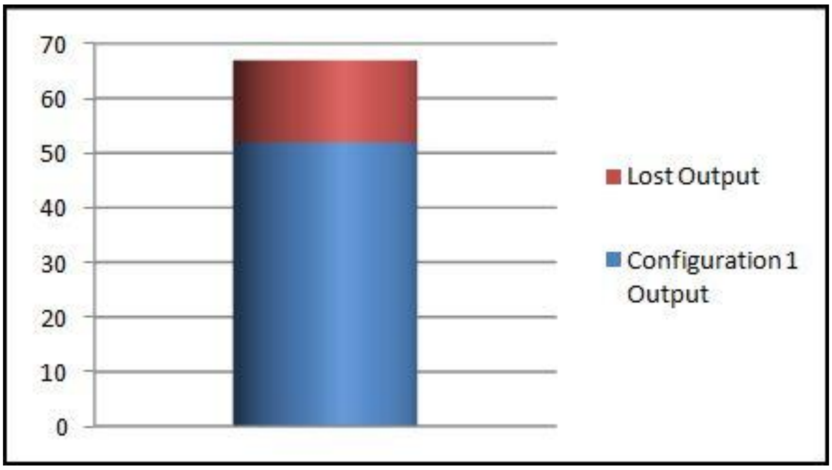

Figure 28 – Configuration 1: Wash Bay Output Lost in Relation to Baseline Model

10.2 Configuration 2

From the results of *Configuration 1* it is clear that the drying process is in need of more man power. *Configuration 2* will now test and evaluate incrementing the size of the vehicle drying team from two workers (the norm) to four workers. The change will be made to and tested on Queue 1 for the sake of consistency. *Configuration 2* is therefore testing the following resource configuration:

- Queue1: 1 Washer; 4 Dryer; 1 Worker Vacuuming
- Queue2: 1 Washer; 2 Dryers; 1 Worker Vacuuming

The Arena Simulation Model needs to have certain changes made to it, specifically to the way in which Queue 1 operates. Firstly, it is necessary to adapt the worker schedule for this Queue. Figure 26 shows that there are now four workers available to dry vehicles.

Figure 29 – Configuration 2: Revised Drying Team Q1 Schedule

Secondly, it must be ensured that the "Vehicle Dry Q1" process module only seizes two workers at a time to dry a vehicle and not all four for one vehicle (Figure 30 – Configuration 2: Vehicle Dry Q1 Module)

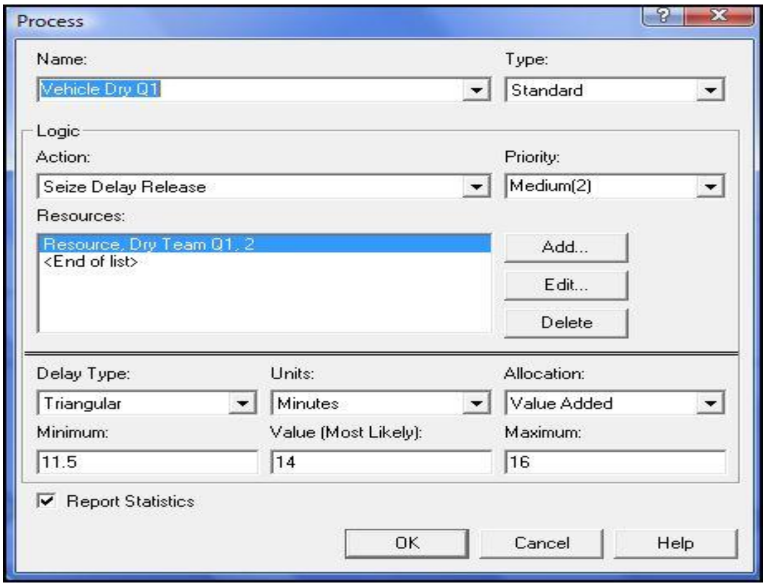

Figure 30 – Configuration 2: Vehicle Dry Q1 Module

With these configuration changes to the simulation model in place we may now discuss the output data which was obtained. Once again, due to the primary change being made to Queue 1, most of the discussion will refer to the impact it has had on this queue.

10.2.1 System Output

Simulation model output provided the following data that can be seen in Figure 28:

Figure 31 – Configuration 2: System Output

Compared with the data obtained from the baseline simulation model we can see that system output has increased by roughly 16.50% from 67 vehicles to 78. The system is now achieving combined output from both queues which exceeds the required number of 75 vehicles. However, we need to further analyse the results to find any bottlenecks and problems which may have been created by this configuration change. The relevant data will now be discussed further.

10.2.2 Entity

Table 6 shows that the average waiting time of a vehicle in the wash bay has decreased by nearly 13 minutes, resulting in a valuable overall reduction in the total average time that a vehicle will spend in the system.

Output Area	Baseline Simulation Model (Minutes)	Configuration 2 (Minutes)
Average Waiting Time Queue 1	126.18	113.26
Total Time Spent in Wash Bay	158.27	145.05

Table 6 – Configuration 2: Average Total Waiting Time and Total Time of an Entity in Queue 1

10.2.3 Process and Queuing Times

Table 7 contains selected data of the average waiting and total times of vehicles at each process:

Output Area	Baseline Simulation Model (Minutes)	Configuration 2 (Minutes)
Average Waiting Time Per Entity:		
1) Vehicle Dry Q1	54.4929	1.3242
2) Vehicle Vacuum 1 Q1	8.4033	37.5536
3) Vehicle Wash Q1	5.3989	11.4389
Average Total Time Per Entity:		
1) Vehicle Dry Q1	68.4802	14.9792
2) Vehicle Vacuum 1 Q1	18.69	47.5636
3) Vehicle Wash Q1	13.3623	19.4987

Table 7 – Average Waiting and Total time Spent by Entities at individual Processes

Table 8 is a summary of selected average waiting times as well as certain maxima values that were recorded at each of the individual process queues in Queue 1.

Output Area	Baseline Simulation Model (Minutes)	Configuration 2 (Minutes)
Average Waiting Time In Queue:		
1) Parking Q1	83.5156	75.9862
2) Vehicle Wash Q1	5.3989	11.4389
3) Vehicle Dry Q1	54.9332	1.3242
4) Vacuum 1 Q1	8.4033	37.6889
Average Number Of Vehicles Waiting in Queue		
1) Vehicle Dry Q1	3.7841	0.1185
2) Vacuum 1 Q1	0.2801	3.3031
Maximum Recorded Value	**Baseline Simulation Model (Number of Vehicles)**	**Configuration 2 (Number of Vehicles)**
1) Vehicle Dry Q1	6	1
2) Vacuum 1 Q1	2	6

Table 8 - Configuration 2: Entity Queue Data at Selected Points in Queue 1

From the results displayed in the tables above we can see that this configuration has achieved a significant reduction in the:

- Waiting time of vehicles that are parked and waiting to enter the valet cycle as well as those that are queuing to be dried
- Maximum number of vehicles that were recorded waiting in the queue to be dried

At the same time, this configuration has resulted in an increase in the:

- Average waiting time for vehicles at the wash and vacuum processes
- Maximum number of vehicles that were recorded waiting in the queue to be vacuumed

Analysis of the above mentioned trends allows us to conclude that the increase in the size of the vehicle drying team has inherently aided the drying process in becoming more efficient by reducing the waiting times of vehicles as well as the size of queues involved in the vehicle drying process. This has however resulted in an influx of vehicles into the vacuum area. Due to there only being a single worker present to vacuum vehicles, one can deduce that the over-constraint of this worker has been a cause of the dramatic increase in the average waiting time and maximum number of vehicles that have been recorded in this part of the wash bay. This will be proven in the next section regarding resource utilization. The changes to the recorded values for the vehicle wash process have remained virtually unchanged and have therefore not been discussed further.

10.2.4 Resource

Table 9 contains summarized data relating to the scheduled utilization of selected workers in the wash bay.

Output Area	Baseline Simulation Model (Percentage)	Configuration 2 (Percentage)
Scheduled Utilization Of Workers		
1) Wash Team Q1	70.59%	81.59%
2) Dry Team Q1	99.60%	70.13%
3) Vacuum Team Q1	86.52%	93.67%

Table 9 - Configuration 2: Resource Utilization Data

The results show a decrease in the utilization of the vehicle drying team, this is due to the fact that the team size has doubled and therefore their performance capacity has been increased dramatically. This has a direct effect on both the wash and vacuum processes.

Seeing as the drying process was the primary constraint in the baseline simulation model, improved throughput thereof has resulted in an increase in the number of vehicles that are being drawn into the valet cycle. Figure 29 shows that there are now 86 vehicles that are being drawn into the system, which is up from the 84 which were being drawn in before.

Vehicle Wash Q1	51.0000
Vehicle Wash Q2	35.0000

Figure 32 – Number of Vehicles Entering the Wash Processes (Number of Vehicles Being Drawn Into Valet System as a Whole)

This, and the fact that the congestion which the drying process was causing in the *baseline simulation model* has been relieved, has resulted in more vehicles being washed and exiting the wash process. Fewer vehicles are now just standing parked waiting to move on to the drying process. As a result there has been an increase in the scheduled utilization of the vehicle wash team. However, the utilization is only at 81.59% which clearly indicates that the wash process is capable of processing a few more vehicles.

The vacuuming process has had no change in its resource capacity, this combined with a greater influx of vehicles from the washing and drying process has resulted in near over utilization of the vacuum team.

10.2.5 Conclusion

The changes that have been proposed and tested in *Configuration 2* have yielded successful results. The wash bay is now capable of completing 78 vehicles on a daily basis, which falls within the acceptable limits. However, it is necessary to test further configuration changes (using *Configuration 2* as a baseline) based on the data and trends which have been observed.

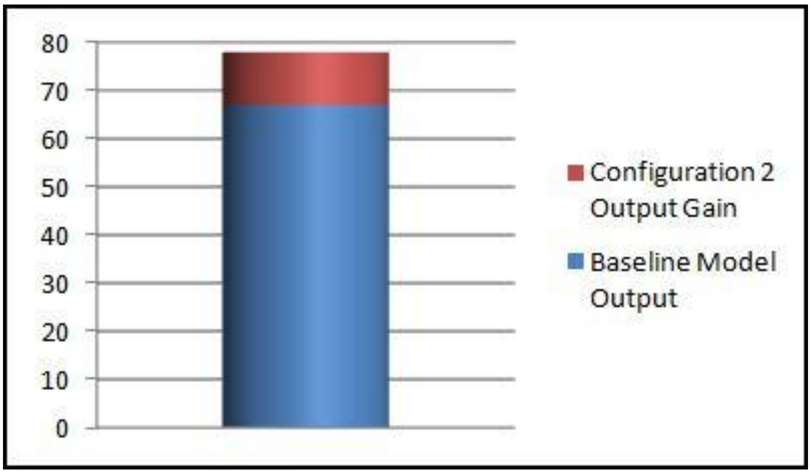

Figure 33 - Configuration 2: Gain in Wash bay Output

10.3 Configuration 3

From the results of *Configuration 2* the next logical set of actions would be to test the effect of:

1) Allowing the Queue 2 vacuum team to assist in Queue 1 (when the team in Queue 2 is in the idle state)
2) Employing an additional worker to vacuum vehicles

It is however easy for one to get carried away in a virtual world where money is not a factor. In reality the costs of employing additional workers and even proposing certain changes are just not feasible. Due to practical and economic Constraints, as well as comparison between the costs that would be involved and the performance gains that would be achieved, the two configurations that were proposed above have been dismissed. Reasons for each will now be explained.

10.3.1 Queue 2 Vacuum Team Assists in Queue 1 When in Idle State

In *Configuration 2* we witnessed 86 vehicles entering the wash bay processes, while 78 were exiting. It was seen that the scheduled utilization of the vacuum team in Queue 1 (The Queue that was selected for testing of the proposed changes) is very high. At the same time, the average waiting time of vehicles at the vacuum process saw a dramatic increase. At the end of the work day there were still four vehicles trapped in the vacuum process of Queue 1.

From the output data of *Configuration 2* we see that the vacuum team in Queue 2 has a scheduled utilization of nearly 68% (See Appendix C). One may therefore consider trying to utilize this team further by letting those workers vacuum cars in Queue 1 when they are idle. This however will create a new set of challenges, which are listed below:

- There is a risk that workers may be over utilized due to the fact that they will be serving Queue1 and Queue 2
- The vacuum team receives vehicles directly from the drying process; however when there are 5 vehicles waiting to be dried then the vacuum team technically receives vehicles that arrive directly from the wash process. If we look at data obtained from *Configuration 2* (Figure 30) we see that the minimum total process time per vehicle of the wash and dry process in Queue 2 is 6.9038 minutes and 12.7167 minutes respectively.
- The time distribution used in the simulation model for the vacuum process is:
  Min = 6 Min
  Most Likely Value = 9 Min
  Max = 14 Min

Total Time Per Entity	Average	Half Width	Minimum Value	Maximum Value
Vacuum 1 Q1	47.5636	(Insufficient)	8.1264	114.05
Vacuum 1 Q2	16.6335	(Insufficient)	7.7272	76.3098
Vacuum 2 Q2	18.4679	(Insufficient)	7.3927	79.7286
Vehicle Dry Q1	14.9792	(Insufficient)	12.2721	79.9869
Vehicle Dry Q2	63.1140	(Insufficient)	12.7167	132.37
Vehicle Wash Q1	19.4987	(Insufficient)	6.9611	85.5318
Vehicle Wash Q2	17.1302	(Insufficient)	6.9038	68.0132

Figure 34 – Configuration 3: Total Average, Minimum and Maximum Process Times Per Entity

As a result, it is apparent that the situation may arise on more than one occasion per day where a worker in Queue 2 will be idle and begin vacuuming a vehicle in Queue 1. The worker will then be in the busy state in Queue 1, while a vehicle will arrive for vacuuming in Queue 2 from its wash and drying processes. This will therefore create congestion and hinder the performance of Queue 2, as well as having an overall negative effect on the efficiency of the entire wash bay.

Testing of such a configuration can already be seen to be infeasible, impractical and would waste unnecessary time. Leaving the operating logic of Queue 2 unchanged, and thereby still maintaining a scheduled worker utilization of 68%, will also leave room and spare capacity for this queue in the future.

10.3.2 Employing an Additional Worker to Vacuum Vehicles

One may think of advising the employment of another worker to vacuum vehicles. There would be two options regarding his condition of employment, namely:

- This worker will only vacuum vehicles in Queue 1
- This worker will act as a "floating" resource which can be utilized by both Queue 1 and Queue 2 for the vacuuming of vehicles

One should however view such an employment suggestion in context. It was found in *Configuration 2* that it is beneficial to employ two extra workers to dry vehicles, which would resulted in a 16.5% increase in daily vehicle process output. Seeing as there are only four vehicles that remain in the process to be vacuumed, it does not justify employing a worker simply to achieve this 5% increase in throughput. The space limitation in the combined drying and vacuuming area is a major factor that also needs to be considered. One may employ an extra worker, yet the space constraint may limit any benefits that may be gained from the increased vacuum process's resource capacity.

10.3.3 Conclusion

When conducting simulation modelling it is important to set certain boundaries which will limit ones imagination, and allow practical and financial factors to be adhered to. The sensitivity analysis will therefore now move away from testing fluctuations in the wash bays resource capacity, and will investigate minor changes to the facility's layout.

10.4 Configuration 4: Testing Changes to Facility Layout

Due to the wash bay being located in a confined area it is crucial that the available space is utilized to its full potential. Through investigation and observation one can deduce that building on to the existing facility is not an option with respect to the relatively minimal improvements in process performance that are required, even without considering the great economic impact of such a decision. Therefore an innovative measure with acceptable practical consequences would have to be taken if more space was desired in the wash bay. Two changes will now be proposed and tested, namely:

- Increasing the capacity of the wash area from three vehicles to four
- Increasing the capacity of the drying and vacuuming area from seven vehicles to eight

10.4.1 Increasing Wash Area Capacity

It was discovered that the high pressure hose has a lead that is long enough to extend outside of the covered area (Which can accommodate three vehicles at a time). We can therefore change the operating logic of the model to simulate the situation where the worker can have up to four vehicles in the wash area at any point in time. The model will allow for the situation where some vehicles wait to be washed while others are parked and waiting to move on to the drying process.

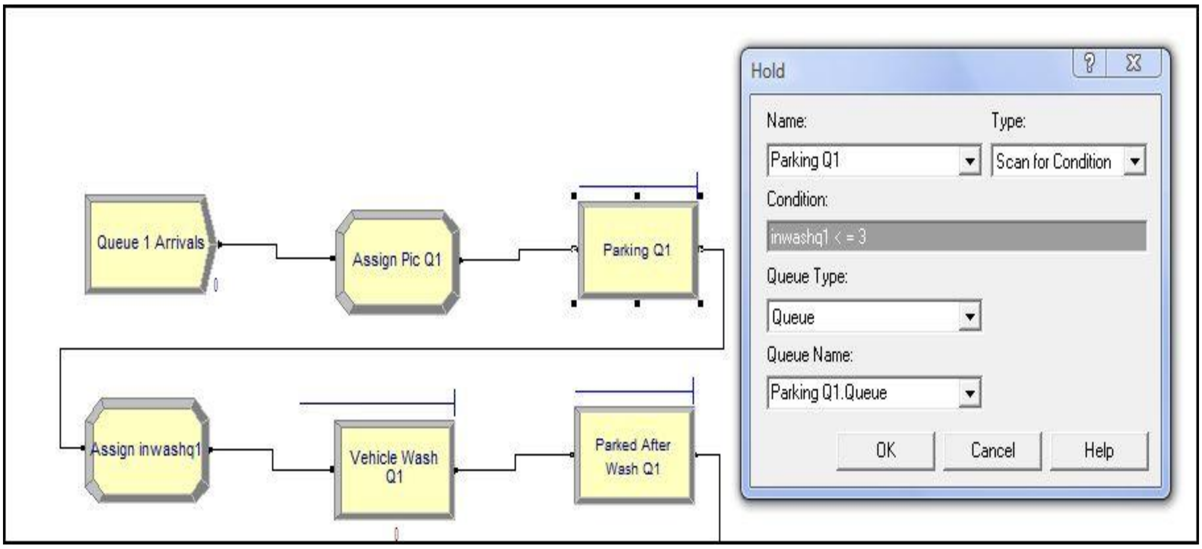

Figure 35 – Configuration 4: Revised Parking Q1 Hold Module

Figure 31 shows that a modification to the "Parking Q1" Hold Module is all that is required to simulate an increase in the capacity of the vehicle wash area. The expression "onwashq1" monitors the variable "inwashq1" (the number of vehicles present in the wash area) and allows a fourth vehicle to enter, whereafter other vehicles will wait in the parking area.

The necessary data output obtained from the simulation model will now be discussed.

10.4.1.1 System Output

Simulation model output provided the following data that can be seen in Figure 32:

System	Average
Number Out	78

Figure 36 – Configuration 4: System Output for Increased Wash area Capacity

System output has seen no improvement, or worsening from the addition wash area capacity. This finding will now be investigated further.

10.4.1.2 Process and Queuing Times

Number In	Value
Vacuum 1 Q1	53.0000
Vacuum 1 Q2	20.0000
Vacuum 2 Q1	0.00
Vacuum 2 Q2	18.0000
Vehicle Dry Q1	54.0000
Vehicle Dry Q2	37.0000
Vehicle Wash Q1	54.0000
Vehicle Wash Q2	38.0000

Figure 37 – Configuration 4 Increased Wash Area Capacity: Number of Entities Entering Individual Processes

Number Out	Value
Vacuum 1 Q1	47.0000
Vacuum 1 Q2	20.0000
Vacuum 2 Q1	0.00
Vacuum 2 Q2	17.0000
Vehicle Dry Q1	53.0000
Vehicle Dry Q2	31.0000
Vehicle Wash Q1	54.0000
Vehicle Wash Q2	38.0000

Figure 38 - Configuration 4 Increased Wash Area Capacity: Number of Entities Exiting Individual Processes

From Figure 34 we can see that we now have 92 vehicles being drawn into the wash bay processes, 6 more than in *Configuration 2*. We saw that the system still however only completes 78 vehicles on a daily basis, indicating that there is a bottleneck somewhere in the system.

By comparing the number of vehicles entering (Figure 33) and exiting (Figure 34) the respective process we will be able to pinpoint bottlenecks that has arisen form this configuration change. The following is a summary of this comparison:

- 6 Vehicles remain in the Vacuum 1 Q1 Process
- 1 Vehicle remains in the Vacuum 2 Q2 Process
- 1 Vehicle remains in the Vehicle Dry Q1 Process
- 6 Vehicles remain in the Vehicle Dry Q2 Process

We see that Queue 2 is still unable to perform any better due to a restricted vehicle drying process, and that the washing and drying processes of Queue 1 are able to cope with the increased through flow of vehicles, however congestion is being caused by the vacuum process.

10.4.1.3 Resource

Table 10 contains summarized data relating to the scheduled utilization of workers in the wash bay.

Output Area	**Configuration 2 (Percentage)**	**Configuration 4 (Percentage)**
Scheduled Utilization Of Workers		
1) Wash Team Q1	81.59%	86.76%
2) Dry Team Q1	70.13%	73.39%
3) Vacuum Team Q1	93.67%	93.67%
4) Wash Team Q2	55%	60.52%
5) Dry Team Q2	88.14%	88.30%
6) Vacuum Team Q2	67.44%	76.56%

Table 10 – Configuration 4 Increased Wash Area Capacity: Resource Utilization Data

The table shows that the scheduled utilization of all workers, except that of the vehicle drying team in Queue 1, has increased.

10.4.1.4 Conclusion

This configuration sees 6 more vehicles being induced into the valet process, while the same number of vehicles is expected to exit as in *Configuration 2*. While the scheduled utilization of workers has risen, one wonders what is causing a hold up in the system. Closer inspection reveals that Queue 1 has 1 vehicle that is waiting to be dried while 6 vehicles which are waiting to be vacuumed. Queue 2 is still unable to deal with a larger volume of vehicles and also has congestion in its drying and vacuuming processes (one must however take into account that the Queue 2 has fewer workers than Queue 1).

It has become apparent that any further changes to the wash bay, which involve increasing the amount of vehicles that the valet system can accommodate, will be limited by the fact that there is simply just not enough time in a day to do more work without increasing the number of staff. As a result, an in depth analysis into increasing the capacity of the vehicle drying and vacuuming area will not take place. However, for future reference the following must be noted. The drying and vacuuming area is bounded on one side by the wash area and on the other by a fence which forms a border between this section of the wash bay and the adjoining level of the parking facility. If this fence is simply moved back, at the expense of a few parking bays, the capacity of the drying and vacuuming area can be increased.

We have identified in *Configuration 3* that there is a need to employ an extra worker to vacuum vehicles in Queue 1 (with regards to *Configuration 2*) and quite frankly Queue 2 could also do with extra employees. The financial impacts of such suggestions, and the fact that *Configuration 2* has already achieved a desirable outcome, will mean that no further configurations will be tested.

A final conclusion and recommendation will follow in *Section 12.1* of this report.

11 Parking Bay Monitoring System

Parking space at Hatfield VW is shared between:

- New vehicles (passenger and some light commercial) that have been delivered from the factory
- Vehicles (passenger) that are waiting to be serviced and those that have been serviced and are waiting for collection
- Vehicles that are waiting to join the wash bay processes for a valet (new or used cars that have been sold and need to be cleaned before delivery to customers)
- Staff vehicles which are parked during office hours
- Avis rental vehicles

The parking facility consists of three levels as well as a shade netted area which is connected to the lower parking level. The structure of the parking lot at present is as follows:

- *1st Level*: For wash bay and service processes only
- *Shade Netted Area*: Mainly new vehicles and used Vehicles that need to be stored; Wash bay and service processes
- *2nd Level*: New passenger and commercial vehicles to be stored; Staff Parking
- *3rd Level*: New passenger and commercial vehicles to be stored; Avis and some Staff Parking

The primary emphasis is that the lower (1st) level of the facility is only for vehicles that are involved in the service and wash bay processes. A new, used or light commercial vehicle that enters the wash or service process may therefore occupy a parking bay on the 1st level. New or used vehicles that need to be stored may occupy any other available space in the facility provided that it is not reserved for staff or avis vehicles. At present it is attempted to group commercial vehicles on the 2nd level; however this is not crucial as space constraints may prohibit this.

There is no system in place at Hatfield VW to monitor the occupation of its parking bays within the facility. Workers simply drive around seeking an open parking bay in which they will then park a vehicle. Sometimes workers park vehicles in places that form bottlenecks and hinder through fare of the facility. Administration also therefore has no means of keeping track of where these vehicles have been parked, which results in an increase in the waiting time of customers that come to collect their vehicles. Upon visiting the facility one can clearly sense the lack of order and well defined procedures regarding parking.

There is a need for a method of monitoring the available parking bays that will allow for adequate tracking of vehicles within the facility and thereby have positive effects such as reducing congestion, minimising customer waiting time when collecting vehicles and allowing Hatfield VW to fully utilize their available parking space.

Road map For the Development of a Parking Bay Monitoring System

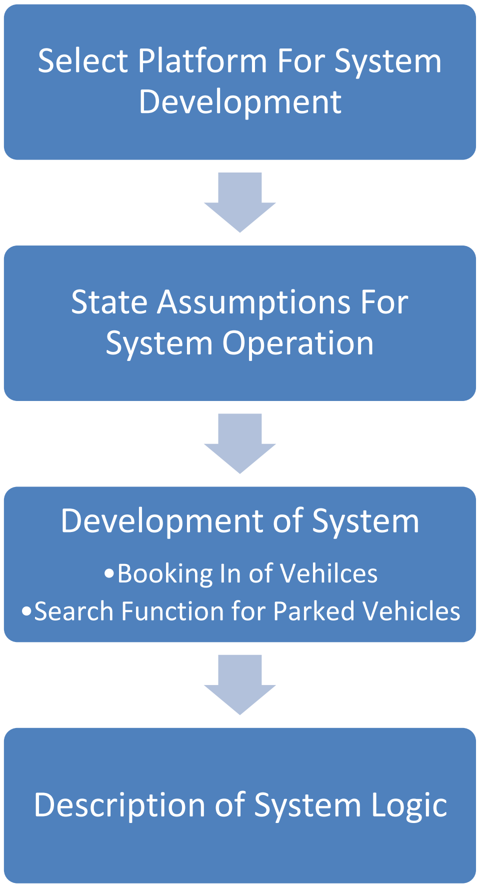

Figure 39 - Road Map Depicting the Processes Involved in the Development of a Parking Bay Monitoring System

11.1 Selection of Platform for Development of System

Hatfield VW only has Microsoft Word and Microsoft Excel on its staff computers. Due to the power and functional ability of Microsoft Excel, it was selected to serve as a platform for the development of a parking bay monitoring system.

11.2 Assumptions

Before construction can commence it is necessary to define the necessary assumptions which will form the operating rules for the system:

- One worker will operate and maintain the system on his/her computer. A co-worker will receive system training, as well as access to the computer on which this system will be run. This will make provision for the event where a worker takes leave or falls ill
- User input must be in the form of upper case characters, without any spaces in-between
- When the user enters a vehicle registration number it must consist of 8 characters
- The system must ask the user to classify the purpose of the vehicles parking requirement. The following options should be available for selection:
  Service: Vehicles that are booked in for service and need parking space for their period of time spent at the facility
  Wash Bay: Vehicles that are just booked in for a valet (New or used vehicles that have been sold and just need to be cleaned before delivery)
  Other: Vehicles (new, used, commercial) that need temporary or long term storage for a variety of reasons. Vehicles are often stored for an indefinite period of time at the facility. Therefore it will not be required from the user to specify a date that the vehicle will exit the facility
- The 1st (lower) level of the undercover parking area will be reserved for vehicles that are involved in the service and wash bay processes
- The 2nd level of the parking lot will not be reserved for commercial vehicles. This will allow vehicles to occupy the respective parking bays in the case where they result in the shortest distance to be travelled in the facility
- Due to the complexity of the shade netted parking area, it will only be used once the three levels of the parking facility are full
- Vehicles must be allocated to an available parking bay that is as close to the entrance of the parking facility as possible. However, it is more important that the bay which is allocated minimises the blockage of other bays. The allocated bay must be displayed to the user in a format of "Level Number +Bay Number"
- Reserved parking spaces must be taken into account (staff and Avis vehicles) and excluded from allocation

- In the case where there are three adjacent parking spaces, and a vehicle that is located in front of others needs to be retrieved, it is deemed to be acceptable that workers will simply move the vehicles that are causing the obstruction
- The user must be able to search for a vehicle that has been booked into the parking facility. Input must be in the form of the vehicles registration number and system output to the user must then be the corresponding parking bay in which the vehicle can be found

11.3 Description of System Logic

11.3.1 Booking in of a Vehicle

Figure 35 shows the user interface in Microsoft Excel for the process of booking a vehicle into the parking facility.

	A	B	C	D	E	F
1						
2	Purpose?		SERVICE			
3	Available Bay		L1P3			
4						
5						
6						
7	Bay/facility:	Level No:	Bay No:	Concatenate	Bay Occupied?	Vehicle Registration Number?
8	1	L1	P1	L1P1	1	MTH593GP
9	2	L1	P2	L1P2	1	ABC123GP
10	3	L1	P3	L1P3	0	
11	4	L1	P4	L1P4	0	
12	5	L1	P5	L1P5	0	
13	6	L1	P6	L1P6	0	
14	7	L1	P7	L1P7	0	

Figure 40 – User Interface for the Booking in of Vehicles

11.3.1.1 Overview

The user is required to enter the purpose of booking the vehicle into the parking facility in cell C2. There are three inputs to choose from, namely:

1) SERVICE
2) WASH BAY
3) OTHER

The system then takes into account the *assumptions* that have been defined and provides the user with output of the nearest corresponding bay which is available (cell C3 and C4). As can be seen in Figure 35 the bay which is available is L1P3 (level one, bay number three. It must be noted that "SN146" would refer to shade netted parking, bay one hundred and forty six). The user must then click on cell E10, and he will then be presented with a drop down list that will allow him to choose a value of "0" or "1". The value of "1" must then be selected to represent that the corresponding bay will now be occupied. The user must then enter the relevant vehicles registration number in cell F10 for record purposes which will be explained in a later section of this paper. A description of how the system works will now follow.

11.3.1.2 How It Works?

Data Repository

Figure 35 shows the user interface which is very simple, user friendly and only contains information that is necessary and relevant to the user. There is however a lot more going on than meets the eye, this data is kept in a separate locked sheet which will be referred to as a "data repository" (Figure 41 – Screen Shot of System Data Repository)

	A	B	C	D	E	F	G	H	I	J	K	L
4												
5												
6												
7	Bay/facility:	Level No:	Bay No:	Concatenate	Bay Occupied?	Vehicle Registration Number?	Concatenate	Value Read	Min Service	Lookup Service	Min Non Service	lookup Non Service
8	1	L1	P1	L1P1	1	MTH593GP	L1P1	10000	3	L1P3	17	L2P1
9	2	L1	P2	L1P2	1	ABC123GP	L1P2	10000				
10	3	L1	P3	L1P3	0	0	L1P3	3				
11	4	L1	P4	L1P4	0	0	L1P4	4				
12	5	L1	P5	L1P5	0	0	L1P5	5				
13	6	L1	P6	L1P6	0	0	L1P6	6				
14	7	L1	P7	L1P7	0	0	L1P7	7				

Figure 41 – Screen Shot of System Data Repository

The sheet displayed in Figure 36 stores all data relevant to the parking lot and is used for performing all of the necessary calculations. The relevant columns will now be discussed.

One can see that columns A to F are exactly the same as those that are found in the user interface.

- *Column A: "Bay/Facility"* uses the facility layout plan (Appendix D) as input which contains all of the bays in the facility listed in ascending order with respect to their distance from the entrance to the parking facility. Therefore a value of 3 means that the corresponding bay is 3rd closest to the parking facility entrance. This will later be used for calculation purposes
- *Column D: "Concatenate"* forms a concatenate using a parking bay number and the corresponding level in the parking facility on which the bay can be found. This will be used for display purposes in the user interface
- *Column E: "Bay Occupied?"* obtains its value from user input via the interface sheet. A value of "0" indicates that a bay is empty and a value of "1" indicates that a vehicle occupies the respective bay
- *Column F: "Vehicle Registration Number"* obtains its value from user input via the interface sheet. It represents the registration number of the vehicle that is occupying a specific bay. This will later be used in a search function
- *Column G: "Concatenate"* is a replication of Column D, and will be used for calculation purposes

Columns H to L contain the calculations that form the crux of this systems operation. These will now be discussed.

- *Column H: "Value Read"* evaluates Column E data to determine whether the respective parking bay is free or occupied. In the case that the bay is free the corresponding value from *Column A: "Bay/Facility"* is displayed. Otherwise a value of 10000 is displayed. This will then allow for a search for the minimum value obtained in this column to take place, which would then identify an available parking bay which is closest to the parking facility entrance. The bays which are occupied and have a value of 10000 will therefore be excluded from this search as their value will always be higher than that of corresponding available bays.
- *Column I:"Min Service"* then searches for the minimum value that is found in *Column H: "Value Read"*
- *Column J: "Lookup Service"* makes use of the following function "=IF (I8<10000, VLOOKUP (I8, A8:D55, 4),"NO PARKING")" to look up the value that was obtained from *Column I:"Min Service* and then display the relevant available parking bays concatenate (Level + Parking Bay Number). In the event that all of the parking bays are occupied the minimum value that will be obtained shall be 10000. In this case the cell will not display a bay concatenate but will instead display "NO

PARKING”. When a user enters either “SERVICE” or “WASH BAY” as the purpose for seeking parking space for the vehicle then the respective free parking bay that will be displayed to the user will be obtained from this cell

- *Column K: “Min Non Service”* operates in exactly the same manner as *Column I:”Min Service”* except that it is used when the user inputs “OTHER” for the vehicles purpose for needing parking space. The minimum value is therefore only searched in accordance with the restrictions that have been mentioned in the assumptions (only service vehicles may be parked on level 1, therefore only other areas of the parking facility are searched)
- *Column L: “Lookup Non Service”* serves the same purpose as *Column J: “Lookup Service”* except that this is now done using *Column K: “Min Non Service”* as input. The function used is “*=IF (K8<10000, VLOOKUP (K8, A8:D55, 4),"NO PARKING")”.* When a user enters “OTHER” as the purpose for seeking parking space for this vehicle then the respective free parking bay that will be displayed to the user will be obtained from this cell

System Over-Ride

If for any reason a vehicle must be parked in a specific bay then the system can be over-ridden. The user must then simply select the corresponding parking bay on the interface, set it to occupied (“1”) and then enter the vehicles registration number.

Reserved Parking for Staff and Avis Vehicles

In the event that specific parking bays must be reserved for staff parking, or avis vehicles, then the user simply has to locate the specific bay on the interface table (Figure 35 “Column D”), specify that the bay is occupied and then enter the vehicles’ details. For search purposes which may take place at a later stage (which will be discussed in the section that follows) the vehicle registration number should be followed by:

- SP to indicate staff parking
- Avis to indicate a reserved spot for an Avis vehicle

11.3.2 Searching For a Parked Vehicle

11.3.2.1 Overview

This system also allows for the user to search for a vehicles location within a parking facility through a second interface (Figure 42 – User Interface for the Searching of Vehicles)

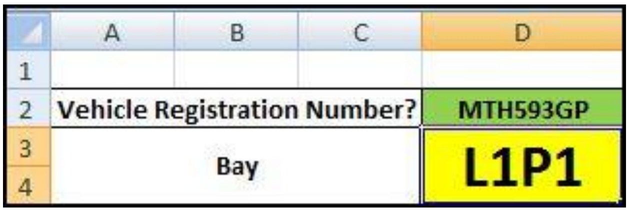

Figure 42 – User Interface for the Searching of Vehicles

This function will be used when:

- A vehicle has been delivered by a customer for a service on a specific day, and it needs to be stored until the mechanics will begin work on it. The mechanic will then need to locate the vehicle in the parking facility
- A customer arrives at Hatfield VW to collect his vehicle. A worker will then have to locate the vehicle in the parking facility before he can deliver it to the customer
- A vehicle has been stored in the facility and needs to be located

The user simply has to enter the vehicles registration number in cell D2 and the corresponding parking bay in which the vehicle has been parked will be displayed to him via cells D3 and D4. In the event that a staff or Avis vehicle must be tracked down, the vehicles registration number should be followed by an “SP” or “Avis” as mentioned previously.

11.3.2.2 How It Works?

Cells D3 and D4 contain the following function:

“=IF (D2="","", VLOOKUP (D2, Data! F8:G55, 2)).

The “VLookup” function identifies the vehicle registration number that was entered in cell D2 and searches for this value in columns F and G of the *Data Repository*. Once this value has been found the corresponding vehicle parking bay concatenate is displayed to the user, informing them in which parking bay in the facility the vehicle can be found.

A final conclusion and recommendation will follow in *Section 12.2* of this report.

12 Conclusions and Recommendations

12.1 Wash bay Configuration

The present wash bay configuration allows 84 vehicles to be drawn into the valet process per day and is capable of achieving an average daily output of 67 vehicles. This is highly inefficient as 17 vehicles remain as work in progress. Hatfield VW seeks a configuration that will see at least 75 vehicles exiting the valet process per day and reduces the mount of vehicles that remain in the system as work in progress.

By employing two additional workers to dry vehicles in Queue 1 the wash bay output will rise by 16.5% to 78 vehicles per day. There will then be an average of 86 vehicles which are entering the system meaning that only 8 vehicles are considered as incomplete at the end of the day, a reduction of 53%.

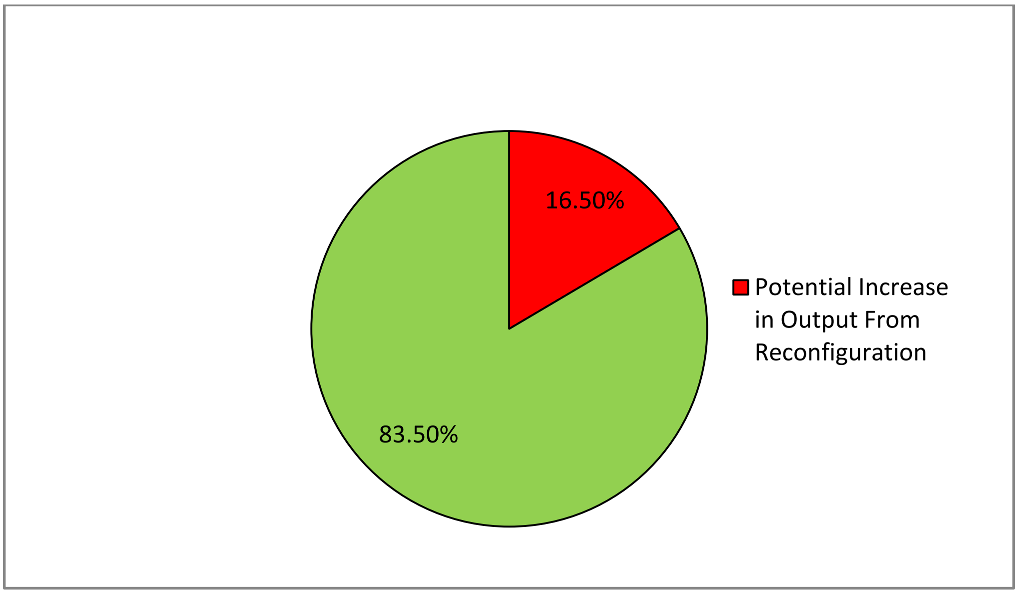

Figure 43 - Potential Increase in Output from Reconfiguration Recommendation

The wash bay currently has no form of supervisor to oversee its various processes. To avoid additional employment costs it is suggested that one of the two workers that move vehicles in between the various queue processes be given the responsibility and authority to supervise the other workers. Ideally an incentive is suggested in the form of a slight raise in this workers salary. The positive effect of supervision was explored in the literature review (*Section 4.9*); as a result it can be assumed that benefits will too be reaped at Hatfield VW. The primary task of the supervisor will be to ensure that workers are performing their various jobs as set out in the chapter containing the job task standardization (*Section 6*) so that the valet system is performing at its optimal efficiency. Secondly, we see that there are 8 vehicles on average which remain in the valet process at the end of each day. With supervision, encouragement and process management from the supervisor this figure could possibly see a reduction and result in average system output of up to 86 vehicles per day.

The implication of these potential increases in valet process output becomes more noticeable when viewed over a period of time. Figure 41 shows the total number of vehicles that would exit the valet process over a period of 10 days. Three scenarios are depicted:

- Present output
- Output after reconfiguration
- Potential output after reconfiguration with the implementation of adequate process supervision

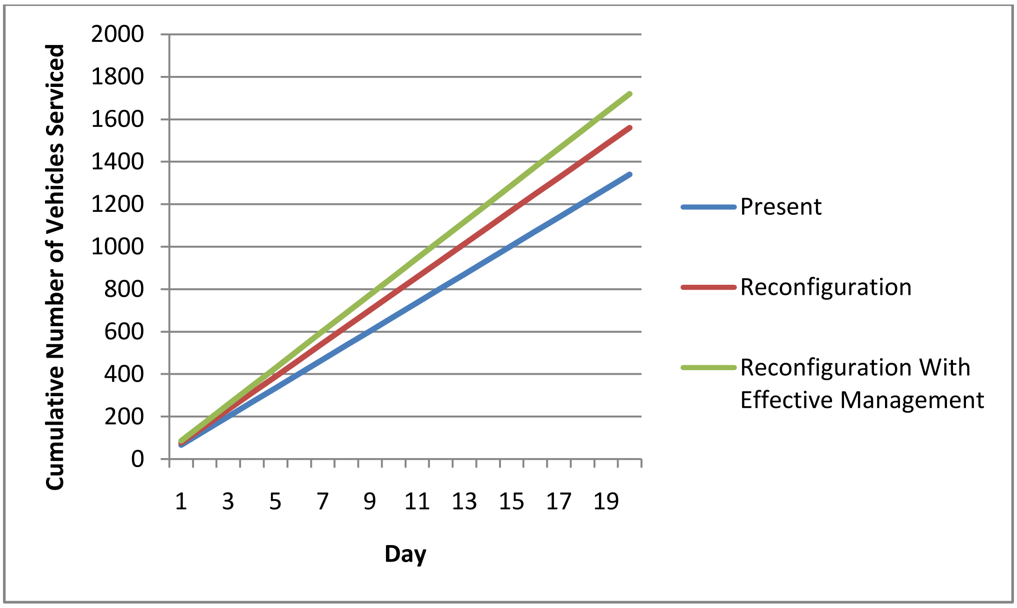

Figure 44 – Cumulative Valet Process Output Potential

We can see that the increase in the valet process's output is quite remarkable over a period of time. Seeing as the wash bay forms part of the greater vehicle servicing process, relief of congestion therein opens up potential for an increased number of vehicles that can be booked in for services (depending on the physical vehicle service process's constraints). Assuming that even just one extra vehicle could be booked in for a service per day, the increase in revenue would be substantial.

There is no need at present to try and expand the capacity of either the wash area or the vehicle drying and vacuuming area.

With the implementation of these suggestions the vehicle wash bay at Hatfield VW will be able to meet its daily required output with ease, and have the potential to go beyond this with adherence to the well defined job tasks and the implementation of effective supervision. This will result in more customers receiving their vehicles on time or even ahead of time and even enable the facility to service more vehicles per day due to reduced congestion in the downstream wash bay processes.

12.2 Conceptual Parking Bay Monitoring System

The parking bay monitoring system that has been presented in this report allows the existing parking space at the facility to be utilized to its full potential and it provides an effective way of locating vehicles that have been parked in the facility. It is user friendly, efficient and will be reliable as long as the worker who is in charge of its operation and maintenance uses it as instructed. Most importantly, this system fulfils an important need that existed at Hatfield VW. Through implementation of this system and proper training of the system users the company will be able to keep track of vehicles that enter and exit the parking facility which will lead to greater efficiency of vehicle processing, faster customer delivery and elevated congestion within the facility.

12.3 Project Summary

This report has identified and thoroughly described two problem areas at Hatfield VW. The literature review then delved into how these areas for improvement came into existence and was used to identify appropriate Industrial Engineering tools and techniques that could be used in the solving thereof. The report then showed how the identified tools and techniques were then adapted to the requirements of this specific project, which lead to:

- Job task standardization
- The development of an optimised vehicle wash bay
- The development of a conceptual parking bay monitoring system

Through the application of fundamental Industrial Engineering knowledge and skills Hatfield VW has been provided with valuable recommendations regarding their vehicle wash bay as well as a system that can be implemented at their parking facility to help administration thereof.

This report has highlighted the benefits that can be reaped as well as the value that can be added to companies in the real world though the logical and correct application of Industrial Engineering methods. More significantly, the value that can be added to companies that not even considered to be related to the field of Engineering.

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Appendices

Appendix A: Time and Motion Study Form Example

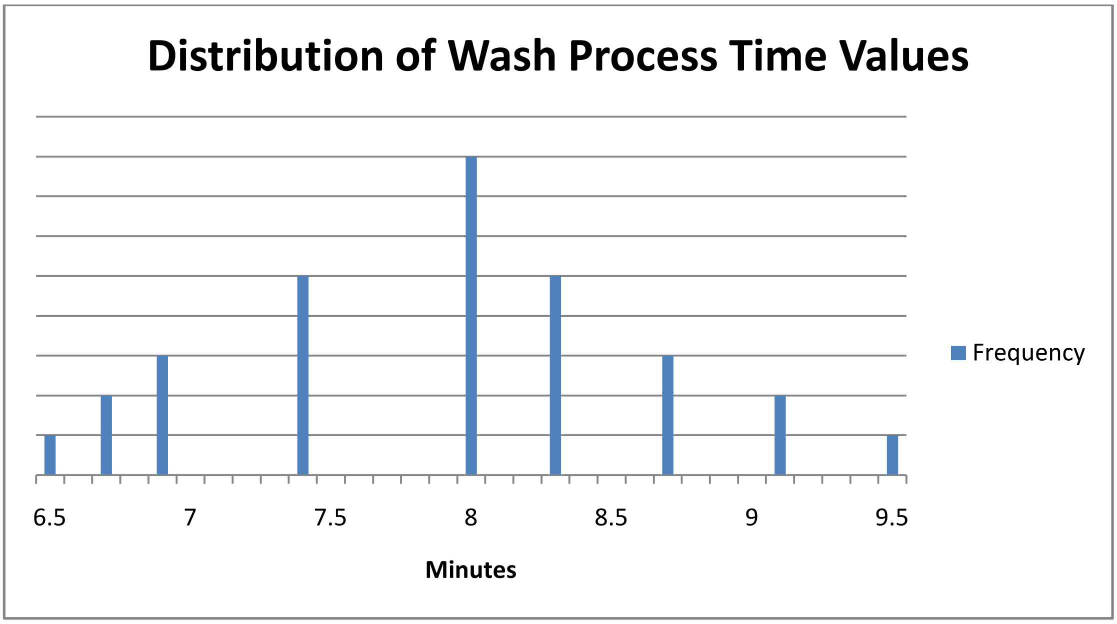
Motion Study Data Collection Form			
Observer:	Michael Pitts		
Obervation:	4		
Date:			
Event	**Worker**	**Order of Operations**	**Notes**
Wash	Washer 2	Bonnet	
		Left Side Roof	
		Right Side Roof	
		Right Side Roof	
		Rear	
		Left Side	
		Wheels	

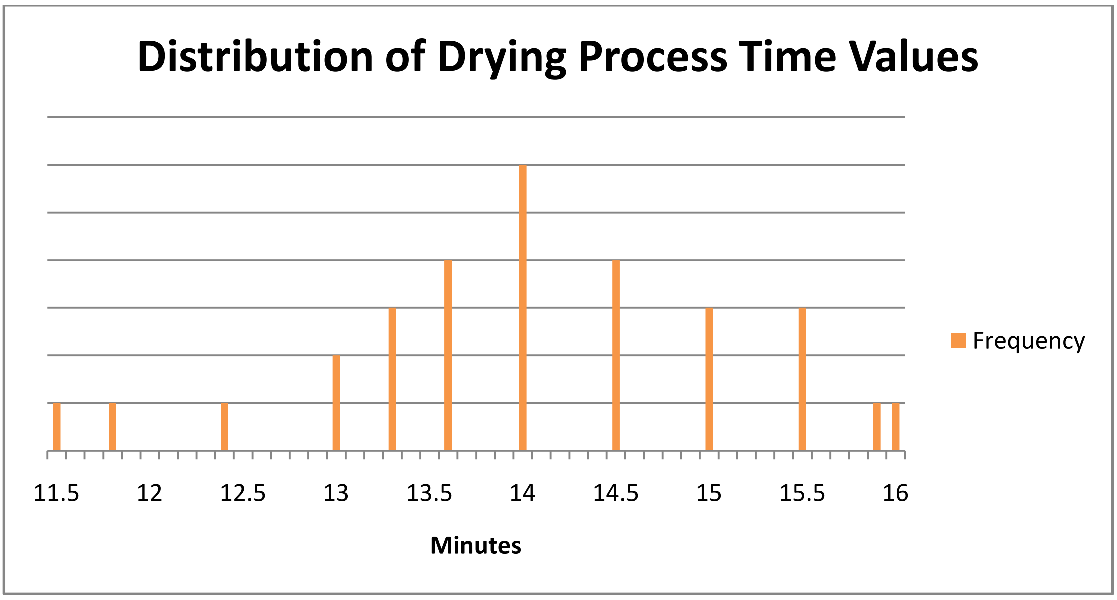
Motion Study Data Collection Form			
Observer:	Michael Pitts		
Obervation:	1		
Date:			
Event	**Worker**	**Order of Operations**	**Notes**
Dry	Dryer 3	Left Front Door	Other member of drying team
		Left Side Roof	dried the right hand side of
		Left Rear Door	the vehilce as well as the
		Boot	bonnet.

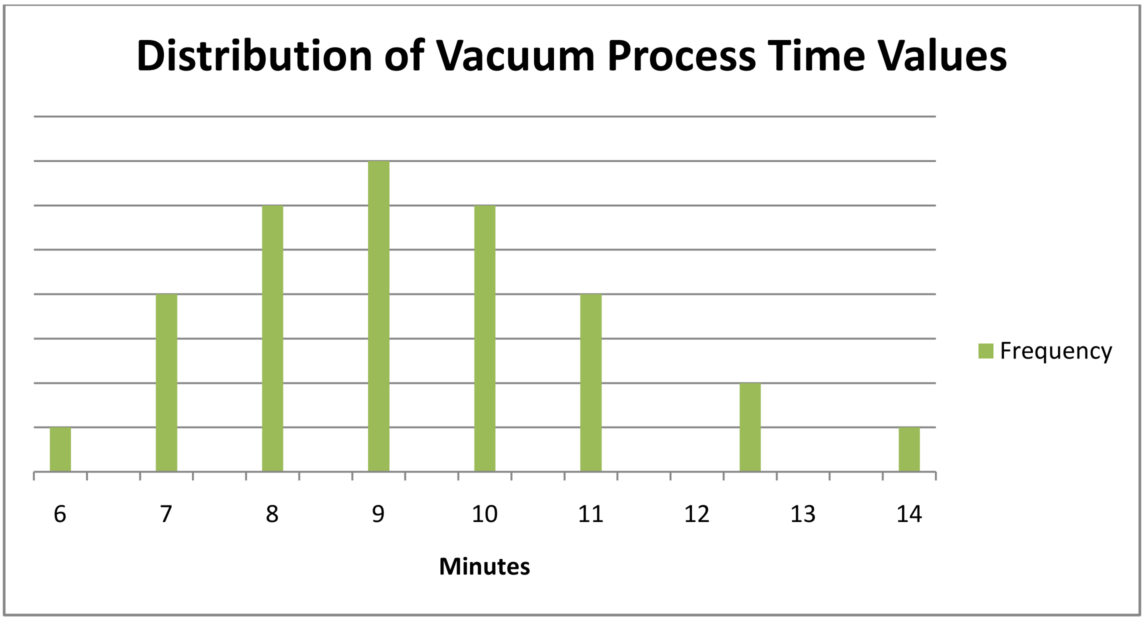
Motion Study Data Collection Form			
Observer:	Michael Pitts		
Obervation:	2		
Date:			
Event	**Worker**	**Order of Operations**	**Notes**
Vacuum	Vacuum 1	Boot	After vacuuming left rear
		Left Rear	worker did not move vacuum
		Right Rear	cleaner, stretched pipe to
		Left front	reach/cleam right rear
		Right Front	

Time Study Form	
Process:	**Vacuum**
Observation number	**Time (Minutes.Seconds):**
1	8.34
2	9.45
3	12.37
4	7.56
5	13.45
6	9.56
7	14
8	6
9	8.55
10	9.5

Appendix B: Process Time Distributions






Distribution of Vacuum Process Time Values
Frequency
6
7
8
9
10
11
12
13
14
Minutes

Appendix C: Configuration 2 Scheduled Worker Utilisation

Scheduled Utilization	Value
Dry Team Q1	0.7013
Dry Team Q2	0.8814
Vacuum Team Q1	0.9367
Vacuum Team Q2	0.6744
Wash Team Q1	0.8159
Wash Team Q2	0.5500

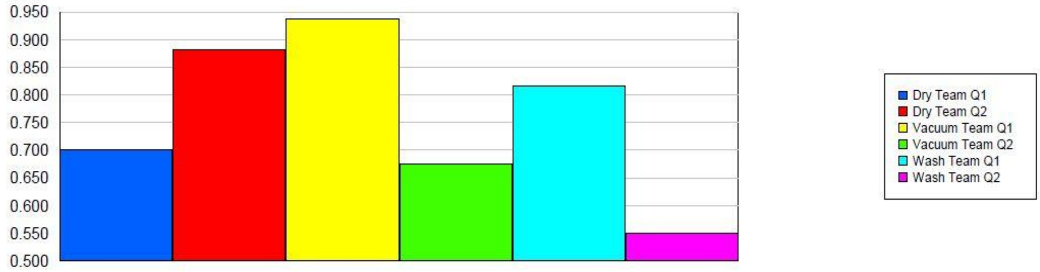


Figure 45 - Configuration 2: Graph of Scheduled Worker Utilisation

Appendix D: Facility Layout Plan

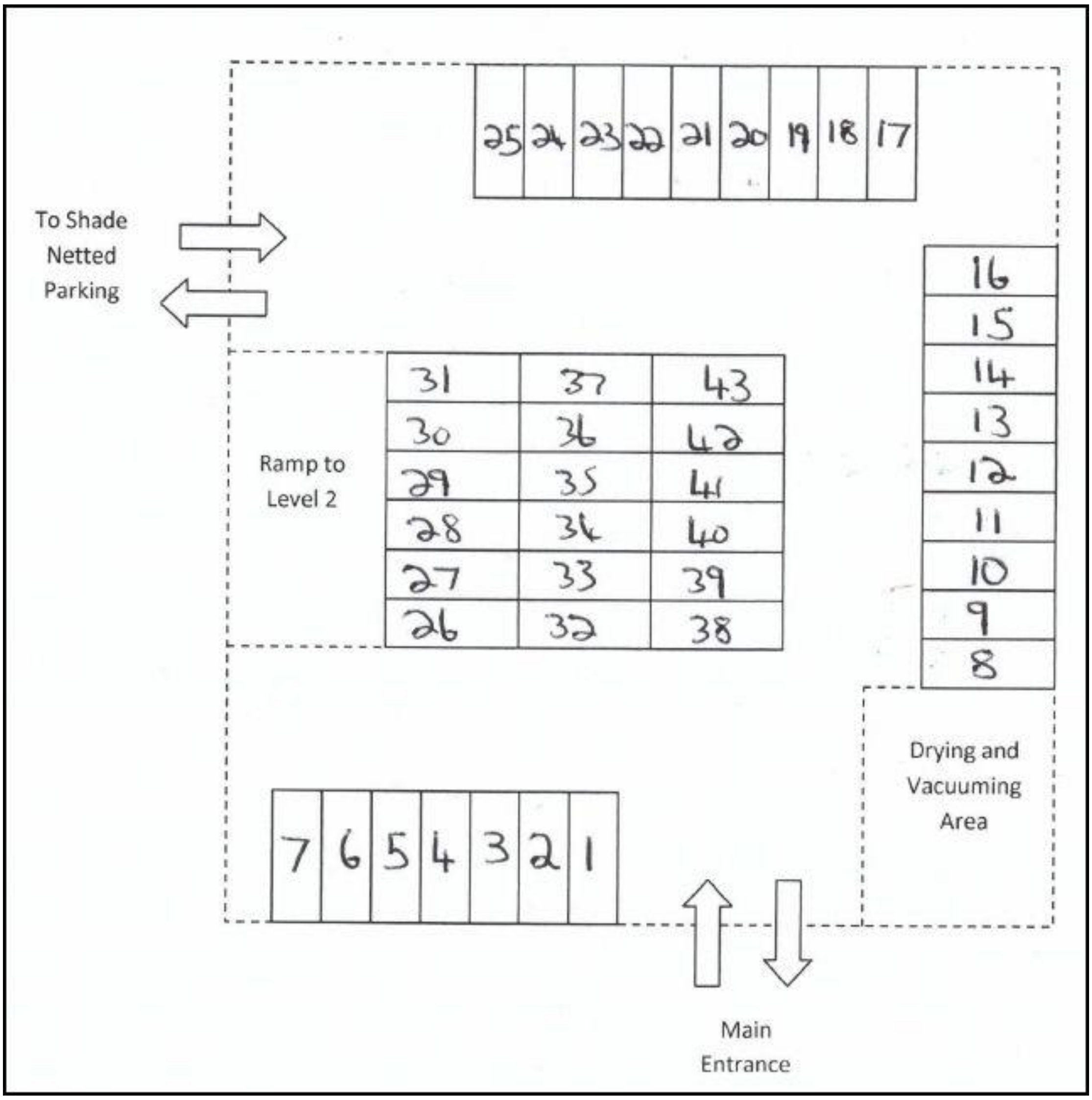


Figure 46 - Parking Facility Level 1

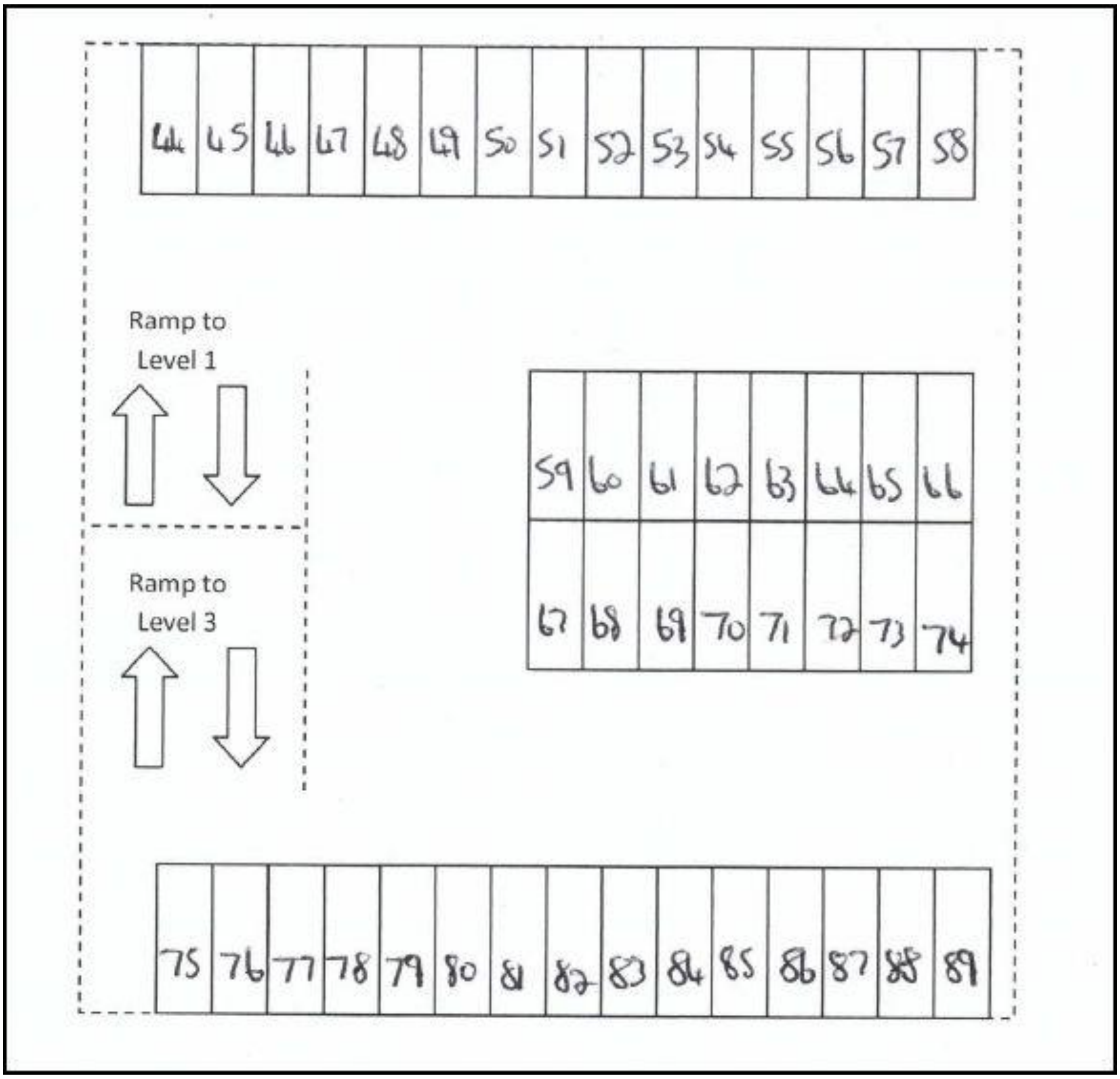


Figure 47 - Parking Facility Level 2

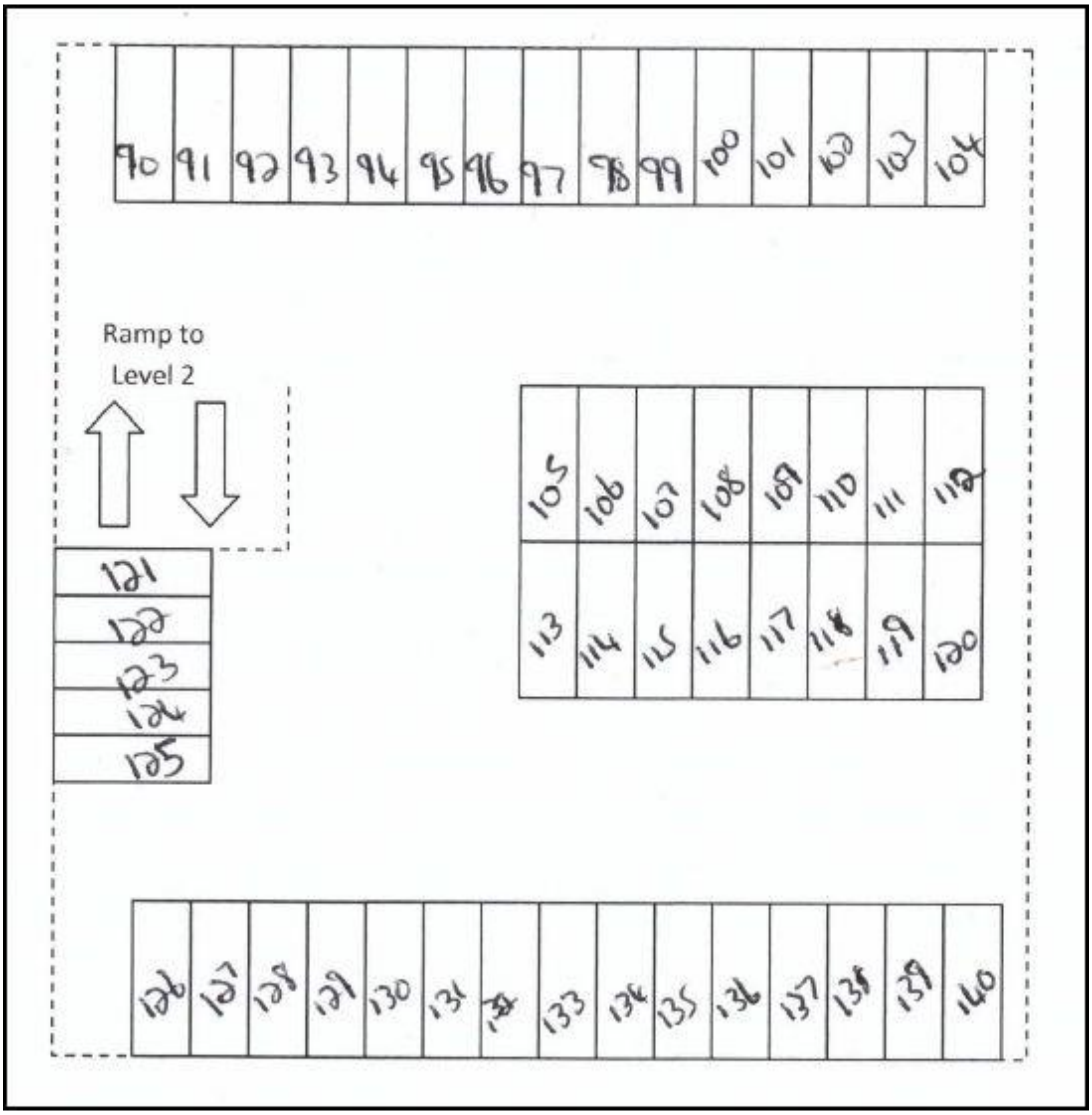


Figure 48 - Parking Facility Level 3

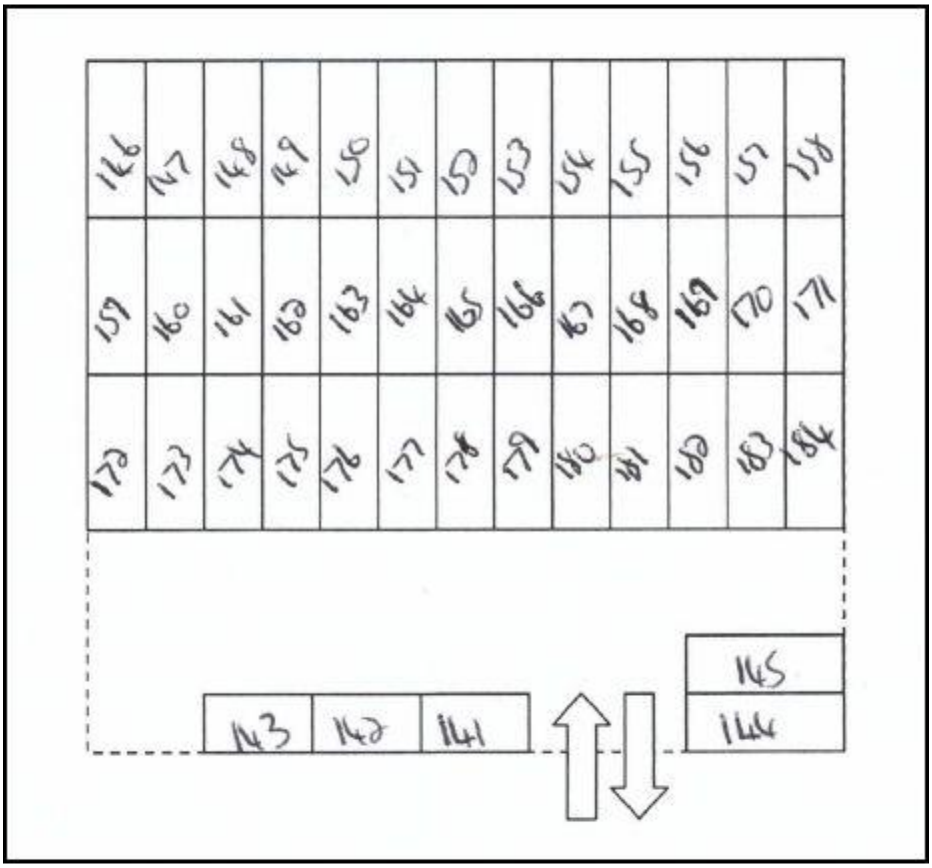


Figure 49 - Parking Facility Shade Netted Area