UNIVERSITY OF PRETORIA

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

BPJ FINAL REPORT

Design of the TuksBaja Production Facility Assembly Line

Author:
Leshanti RAJH GOPAUL
11050293

Supervisor:
Dr. Nico DE KOKER

30 September 2015

Abstract

The project documented in this report addressed the need for the design of a vehicle assembly line layout for the TuksBaja organisation. The project centered around the design and project implementation cycle, typically adopted by engineering projects, that began with proposed layouts for the assembly line, utilised economic analysis and simulation modelling to objectively compare the feasible options, and finally analytic hierarchy principles to select the final design for implementation. This report serves to record the entire project life cycle and concluded that the Modular assembly line layout was the best choice for the TuksBaja Production Facility since it not only met the required production demand the fastest, but was also the most economical option.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

1.1 Project Background

The project at hand is an adaptation of an SAE (Society of Automotive Engineers) Baja competition requirement such that the aim was to design the layout of an assembly line with an output capability of 4000 units (TuksBaja vehicles) per year. Baja vehicles, in short, are four-wheeled, single-seater, off-road recreational vehicles that are designed and produced within a certain set of safety and quality specifications stated in the SAE rules. An example of a Baja vehicle can be seen in Figure 1.1 below.

Figure 1.1: Front and Side views of TuksBaja's Car 2 in action at the South African Baja SAE competition in 2014

As part of the Static Events category of every Baja competition, each team is required to submit a Design and Cost report for their vehicle prototype as well as present to, and convince, a hypothetical board of executives from a hypothetical manufacturing company to purchase their team's Baja vehicle design and put it into production at a rate of 4000 units per year. This project addressed this competition requirement by treating the TuksBaja team as a vehicle production company and this project as a focused study on the assembly division of their production system.

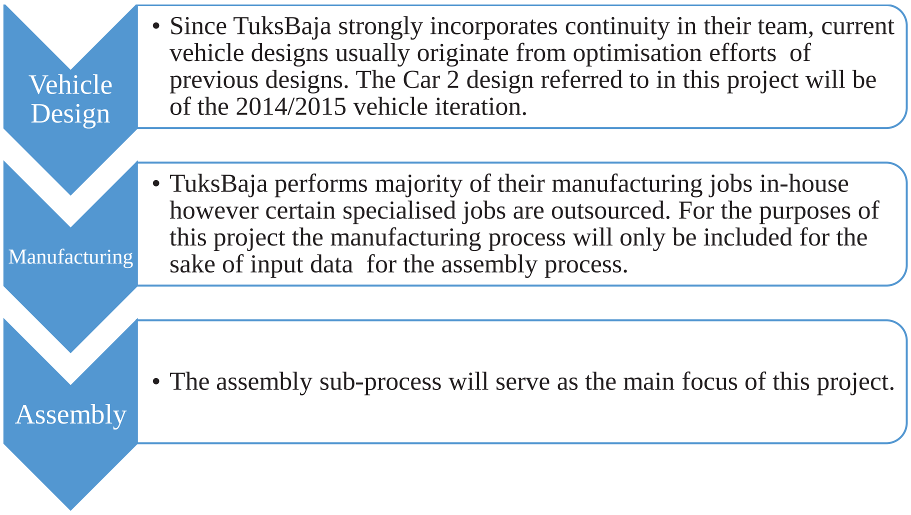
SAE Baja competitions have a total of 3 main categories 'Static Events' (as mentioned above), 'Dynamic Events' and the 'Endurance Race'. Each Baja vehicle entered into the competition, and hoping for success, needs to be able to compete in each category. The Static Events category entails design judging and the examination of the aesthetics and ergonomics while the Dynamic Events includes the acceleration, hill climb, skid pull and manoeuvrability tests. The Endurance Race, which requires the Baja vehicles to complete as many laps around a set race track with various obstacles in 4 hours, usually serves as the main event of the competition. TuksBaja is the representative SAE Baja team from the University of Pretoria.

The Society of Automotive Engineers (SAE) administrates the running of all Baja competitions. There are a number of Baja competitions held across the world every year with the purpose of exposing university students to planning, designing and manufacturing a real world engineering project. TuksBaja competes in the South African competition annually and in American competitions as often as funding allows.

1.2 TuksBaja Production

1.2.1 General

The assembly line layout design revolved around the assembly of one specific TuksBaja vehicle, namely Car 2, which raced in the South African competition in 2014 and will race again in the 2015 South Africa competition in October. The production process for a TuksBaja vehicle, as depicted in Figure 1.2 below, can be divided into three main sub-processes: design, manufacture and assembly.



- Since TuksBaja strongly incorporates continuity in their team, current vehicle designs usually originate from optimisation efforts of previous designs. The Car 2 design referred to in this project will be of the 2014/2015 vehicle iteration.

- TuksBaja performs majority of their manufacturing jobs in-house however certain specialised jobs are outsourced. For the purposes of this project the manufacturing process will only be included for the sake of input data for the assembly process.

- The assembly sub-process will serve as the main focus of this project.

Figure 1.2: Diagram showing the sub-processes of the TuksBaja production process

1.2.2 Car 2

Car 2 is a typical example of a TuksBaja vehicle. It is powered by a 10hp OHV Intek Briggs and Stratton Engine and is fitted with externally adjustable hydro-pneumatic spring dampers, hub reductions and a CVT (continuously variable transmission). Each TuksBaja vehicle runs on petrol and has a theoretical top speed of 55km/h. The first level break down of Car 2 can be seen in Figure 1.3 below.

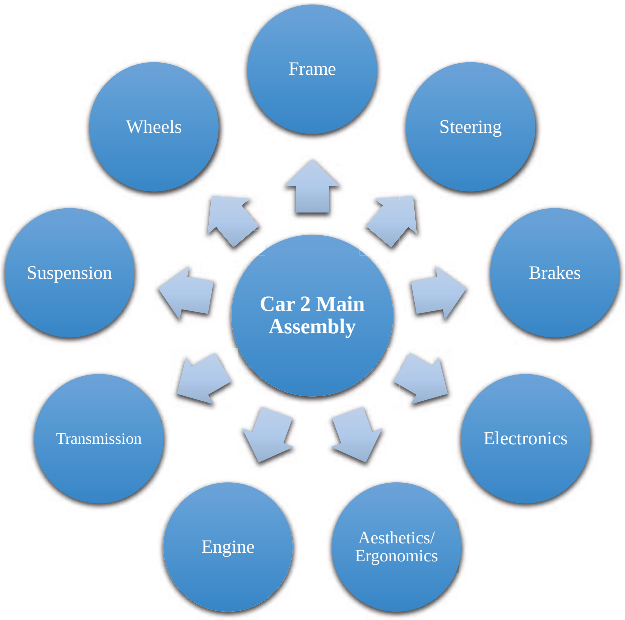


Figure 1.3: Diagram showing the first level break down of the sub-assemblies of Car 2

Figure 1.3 exhibits all the main sub-assemblies that make up the main assembly of Car 2 and the level of sub-assembly depth that has been included in the scope of this project. The full break down of the car and its components may be found in Appendix B. This table was completed with the help of 2014 TuksBaja Captain Kraig Wright via interview on 11 March 2015.

1.2.3 Assembly Process

The current assembly process at TuksBaja relies solely on operators (students) to perform the tasks. Mechanisation of processes is not only costly but contradicts the hands-on learning approach taken by the student-based society. Operators are equipped with the basic tools of a workshop to perform their assembly tasks. TuksBaja, the hypothetical company, could however invest in mechanised processes for the assembly line as a substitute for this manual labour.

In terms of part delivery the situation can be divided into three scenarios. The first refers to parts that have been manufactured in-house. In this case, as soon as the part has been manufactured it is transferred to assembly. In the second and third scenarios external companies are involved. Either the raw material and TuksBaja part drawing is sent to an external company for manufacturing (case 2) or the part is purchased, as is, ready for assembly, from a supplier (case 3). In terms of the scope of this project the different procurement methods only affect the arrival times of parts into the assembly process.

Quality control is undertaken as a continuous effort by all members of the team at every step of the production process as a whole as well as the assembly sub-process.

1.3 Project Definition

The aim of this project was to design the layout of an assembly line with an output capability of 4000 TuksBaja Car 2 vehicles per year. The assembly line refers to the assembly process forming the last sub-process in the TuksBaja production process. This concept has been explained in Figure 1.2 on page 6.

It should be noted that this project was based on the assumption that South Africa averages 250 working days in a year. With this in mind, and the production demand goal of 4000 vehicles per year, it can be concluded that sixteen Car 2 vehicles need to be produced per day in order for the project to reach its main goal.

Chapter 2

Literature Study

The TuksBaja assembly line layout design project is first and foremost a facilities planning project which incorporated the use of simulation modelling and engineering economic analysis, as well as an array of other industrial engineering principles, to help successfully execute the project at hand. Research via journals, textbooks and engineering based magazines was conducted regarding facilities planning of production facilities, especially in the automotive industry, and the following text serves as the literature review for the project.

2.1 Proposed Layouts Design Approach

2.1.1 Requirements Analysis

Before any designing takes place one must first obtain all the necessary space and operational requirements of the facility. This includes safety requirements such as the number and location of emergency exits, minimum allowable distances between machinery/moving parts, minimum aisles widths, etc. One should also consider the possibility of future changes in the design of the product and thus factor in system flexibility and adaptability.

A space utilisation case study, performed specifically for the automotive industry, addresses the need to quantify space requirements in the form of a four step methodology. Figure 2.1 (Bozarth, Vilarinho 2006) on the following page exhibits this methodology. This process aids the layout designer in terms of estimating specific area space utilisation levels of the current system and then translating them to the new design (Bozarth, Vilarinho 2006).

The first step of the methodology involves quantifying current space allocations. This is done by directly contacting plant managers as well as performing on site visits to confirm and/or modify the estimates given by the plant managers. Blueprints and other internal documents are also examined at this stage to produce the base line space allocations for each area.

Step two requires the development of space density factors. Space density factors are defined as the percentage of currently allocated space that is not being utilised. Once again plant managers are consulted and all the floor space that has not been assigned any specific purpose is measured out and then divided by the total floor space measurement to produce the space density factors.

The next step involves the estimation of the impact of production planning procedures. In this step, focus is placed on the plant's inventory and storage levels. A simulation model may be developed around the company's material requirements planning system for a representative sample of production items and the actual demand, orders and inventory records for these products are supplied by the plant managers and incorporated into the simulation model. In conjunction with Excel spreadsheets, that also replicate the material requirements planning logic of the company, future inventory levels, resulting space requirements and the effect of inventory cuts on demand surges are determined. In this way, accurately optimised storage and inventory spaces are designed as well as the correct size and placement of buffers in the plant.

The last step in the methodology requires the estimation of the combined impact of the current space allocations, space density factors and production planning procedures on the new plant space requirements. The results from the first three steps are pooled to gain an all-inclusive view of the actual space requirements of the current plant. Informed decisions can then be made regarding which area space allocations need to remain the same and which can be minimised and to what extent.

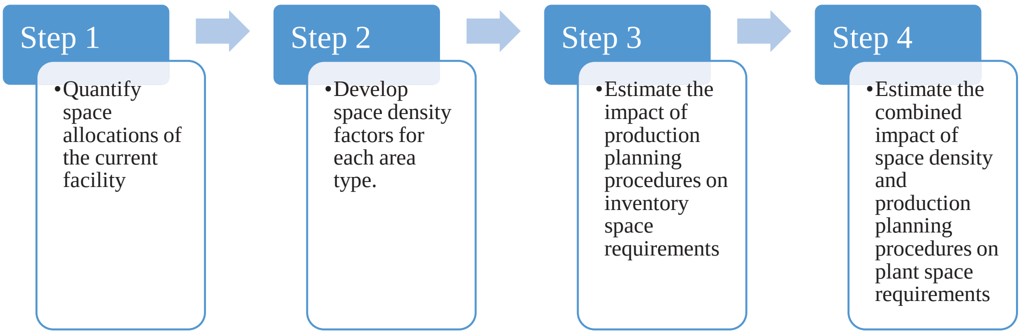
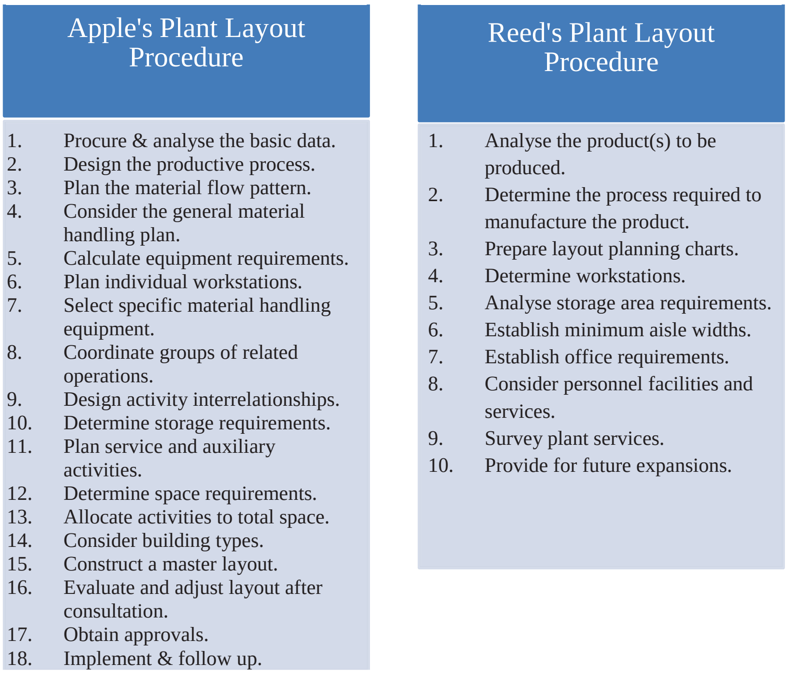


Figure 2.1: Diagram displaying the four step methodology to quantifying space requirements for a facility (Bozarth, Vilarinho 2006)

2.1.2 Layout Design Procedures

A wide variety of procedures addresses the development of alternative layouts. These procedures can be categorised into construction and improvement procedures, construction being the initial design of a layout and improvement being the modification of an existing design. For the purposes of this study, only construction methods of layout alternatives were elaborated on. Some examples are Apple's Plant Layout Procedure (Apple 1977) and Reed's Plant Layout Procedure (Reed 1961) as depicted in Figure 2.2 on the following page. Both Apple and Reed describe the complete cycle, from data capturing and understanding the system at hand to continuous improvement and planning for the future, in a generic methodology making it easy to customise to the designer's needs. While Apple explicitly lays out each step, Reed presents a more summarised view of the project life cycle.



Apple's Plant Layout Procedure

1. Procure & analyse the basic data.
2. Design the productive process.
3. Plan the material flow pattern.
4. Consider the general material handling plan.
5. Calculate equipment requirements.
6. Plan individual workstations.
7. Select specific material handling equipment.
8. Coordinate groups of related operations.
9. Design activity interrelationships.
10. Determine storage requirements.
11. Plan service and auxiliary activities.
12. Determine space requirements.
13. Allocate activities to total space.
14. Consider building types.
15. Construct a master layout.
16. Evaluate and adjust layout after consultation.
17. Obtain approvals.
18. Implement & follow up.

Reed's Plant Layout Procedure

1. Analyse the product(s) to be produced.
2. Determine the process required to manufacture the product.
3. Prepare layout planning charts.
4. Determine workstations.
5. Analyse storage area requirements.
6. Establish minimum aisle widths.
7. Establish office requirements.
8. Consider personnel facilities and services.
9. Survey plant services.
10. Provide for future expansions.

Figure 2.2: Apple (1977) and Reed's (1961) Plant Layout Procedures

Muther's Systematic Layout Planning Procedure (Muther 1973), schematically presented below in Figure 2.3, makes use of activity relationship charts in its foundation phase in conjunction with material flow analysis to produce a relationship diagram. Space requirements in relation to the dominant activities and their interrelations take precedence in this method, which relies not only on objective decision making but also the designer's personal judgement, intuition and professional experience in the facilities planning field (Tompkins et al. 2010).

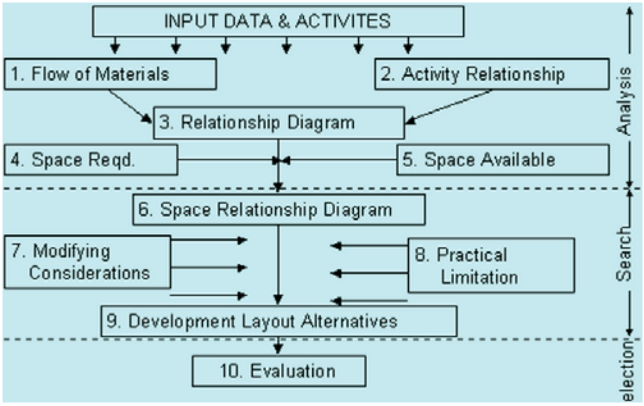


Figure 2.3: Muther's (1973) Systematic Layout Planning Procedure

The Facilities Planning Process, detailed in Figure 2.4 (Tompkins et al. 2010), is a facilities planning adaptation of the traditional engineering design process and is used as the initial approach to designing or redesigning a facility in an organised and systematic way. This process is usually implemented as part of the life cycle of a project and used as part of the continuous development process.

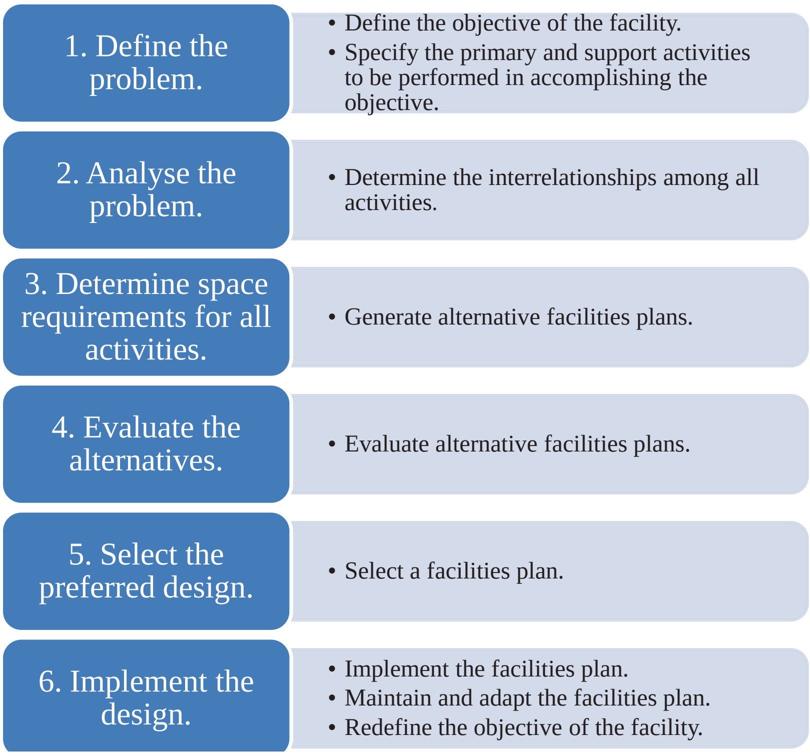


Figure 2.4: The Facilities Planning Process (Tompkins et al. 2010)

Much insight concerning the fruition of the TuksBaja assembly line layout design project can be gained from the General Motors Corporation's Lansing Grand River (LGR) assembly plant. The LGR plant was designed on the principle that for maximum competitive benefits the design of a manufacturing facility must be carefully integrated with production processes in order to meet both product goals and the company's revenue potential (Teresko 2002). Adopting this method of reasoning would not only help realise the TuksBaja production goal but also help to retain focus on the assembly process in the designs which would in turn minimise unnecessary costs and optimise space and resource utilisation.

Even though the LGR plant literature refers to the LGR plant as a whole, the same principle may be applied to just the assembly process of the TuksBaja production plant. The scale is of course smaller and 'production processes' would instead refer to 'assembly processes' however the logic behind the planning remains the same. The actual assembly work would have to remain the project's main focus throughout all the designing and planning in order for each prospective layout in the first deliverable stage to be a success.

2.2 Proposed Layout Types

In terms of assembly layout designs, literature reviewed was focused on three main types of prospective designs, namely U-shaped/Loop flow, Team Production layout and a Modular/Cellular assembly line layout. In general, layouts are based on material flow systems which stem from manufacturing processes and their designs. Two types of flow within a process department have been focused on in this study: flow based around material flow systems and flow based around material handling systems.

Material flow systems refer to the manner in which material, parts, or work in progress moves within the department. Historically the four main types of production planning departments, in terms of material flow systems, are production line/product layout departments, fixed materials location departments, product family departments and process departments (Tompkins et al. 2010). Graphical depictions of each may be found in Figure 2.5 below.

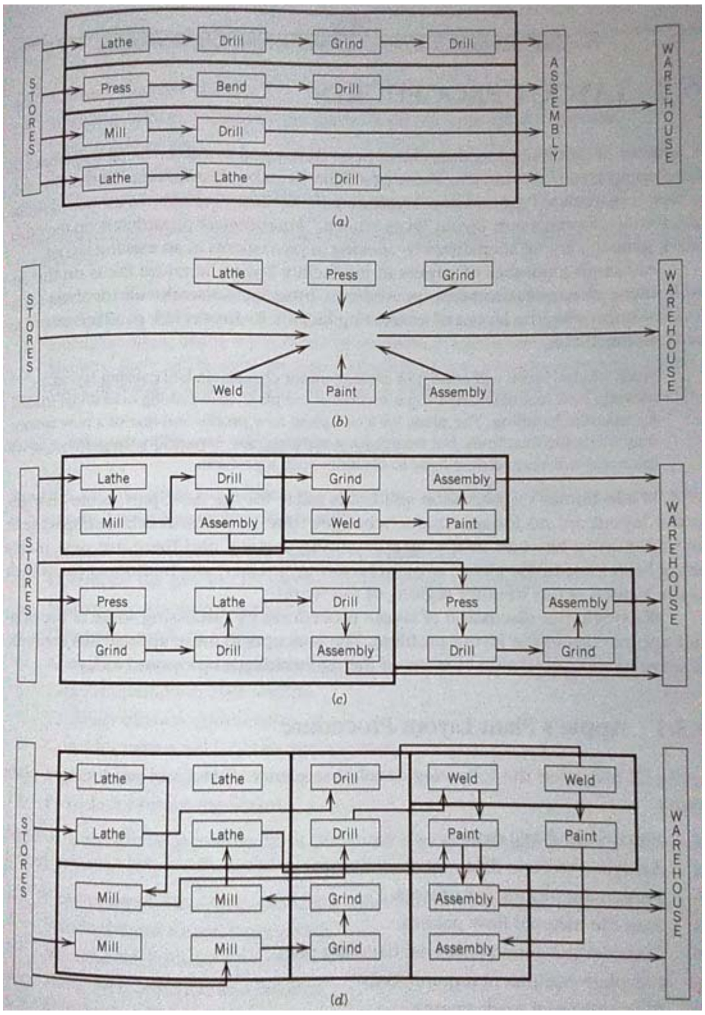


Figure 2.5: Diagram showing the a) production line, b) fixed materials location, c) product family and d) process type layouts (Tompkins et al. 2010)

Production line product layouts are product-orientated, meaning that the flow follows the operation sequence for the product, and are used most commonly for high volume, low variety products. Fixed materials location departments are used in the assembly processes of ships, aircraft and other bulky, construction-type projects. In this layout all the parts and sub-assemblies are brought to the main assembly which remains fixed throughout the process. Product family layouts group parts into 'families' (or cells) based on manufacturing, tooling or general processing requirements and is a good compromise between product and process layouts. Process department layouts groups similar processes together and are best suited for high amounts of machine utilisation.

Flow within process departments refers to the movement of operators and work in progress between workstations in a specific department. Taking into account material handling considerations, flow within process departments can be divided into four main flow patterns: line flow, spine flow, loop flow and tree flow (Tompkins et al. 2010). Examples of line flow patterns are straight line flow, u-shaped flow and s-flow. Many variations of line flow exist and this flow type is popularly used in the automotive production industry. Spine flow employs the use of a central 'spine' that connects workstations on either of its sides and loop flow exists as a closed loop shape with workstations on either the inside or outside of the loop. The tree flow pattern, appropriately named due to its close resemblance to the branches of a tree, also employs the use of a centralised line however instead of just connecting workstations, as in the case of the spine flow, the central line connects smaller lines, each with their own set of workstations.

The selection process of the top three layouts required the review of all possible layouts while considering both material handling systems and material flow systems. TuksBaja falls within the automotive industry however the parts, and even sub-assemblies, are light enough to not require any specialised material handling equipment and so more emphasis was placed on the material flow needs over the material handling needs. As a result, two layouts in the material flow category were chosen for further research and development: the Team Production layout (a variation of the fixed product layout referred to above) and the Modular layout. The modular layout is conventionally a combination of the product family department layout (sometimes referred to as cellular manufacturing) and the tree flow layout, however in this situation the layout modified to suit the project has drawn more elements from the product family layout. The third layout chosen was the U-shaped layout which stems from loop flow and thus centres around material flow systems. A U-shaped assembly line was chosen over the other line flow options due to the variety of advantages afforded by this shape that shall be explained in the sections to follow.

2.2.1 Team Production

Team-oriented assembly systems essentially make use of semi-autonomous teams with well-defined work descriptions. The job at hand is either performed entirely, from start to finish, by a single team and then replicated across the production environment or split into its major subsystems with the same production methodology as previously mentioned. The system established incorporates a product-orientated approach and performance measures within each team, and between teams, is encouraged (Bukchin, Darel and Rubinovitz 1998).

2.2.2 Modular

Modular assembly line layouts, a combination of the Tree Flow Pattern and Cellular Manufacturing technique (Tompkins et al. 2010), can be characterised as a process layout with workstations positioned in a single/multiple trees linked together by a centralised material handling structure. This design is usually found in facilities that employ robotic material handling devices for the product/part movement between workstations and is popular in the automotive assembly industry.

Modular assembly lines are said to improve throughput by increasing the efficiency of the parallel sub-assembly lines which feed into the main/final assembly line. Cellular Manufacturing is usually utilised in the manufacturing division of systems where machines, operators, materials, tooling and/or storage of the same type/function are grouped together in 'cells'. This technique incorporates clustering methodologies to group parts together so that they may be processed in their respective groups. Clustering lists parts and machines in rows and columns and interchanges them based on certain predetermined criteria. Modularity thus implies a dispersed assembly system since activities are split into main/final assembly and pre-assembly categories (Fredriksson 2006).

2.2.3 U-shaped/Loop Flow

Loop flow can be identified by a U-shaped process line with service stations attached to it either on the inside or the outside of the loop (Tompkins et al. 2010). U-shaped assembly lines in particular have their service stations located on the outside and the operators for the process line collected on the inside. This allows for easier communication in comparison with the traditional straight line design. The u/loop shape allows for greater visibility and transparency within the subsystem as well as the opportunity for a single operator to perform multiple tasks, easier change overs at the end of shifts and simplified cross training of new operators (Miltenburg 2000). Operators are thus required to be multi-skilled and usually standing or walking around. Operations are arranged on the line in their sequential order and often the same operator supervises both the entrance and exit of the line. Machine work is performed independently from assembly work and no unfinished pieces are permitted to leave the line.

2.3 Simulation Model, Economic Analysis and Final Decision Making Process

As part of the LGR plant, General Motors also incorporated simulation modelling into their facility planning phase. They built a 'virtual factory' which helped to refine system relationships and provide validation at minimal cost, thereby reducing developmental costs (Destefani 2003).

The same approach was taken with the TuksBaja assembly line layout design project to gain the same perspective and insight into the finer workings of the system relationships involved in the assembly process, with the end goal of determining the time needed for each design to meet the production goal as well as the total space needed. Simulation models, and the experimental runs conducted through each model, provided these answers as well as the necessary validation data to support the ensuing decisions.

Since no project may be conducted without financial constraints and considerations, most literature reviewed alluded to economic analyses that were performed. The selected method of financial decision making was the cost-benefit analysis technique. Cost-benefit analyses have three goals: to maximise the benefits for any given set of costs, to maximise the net benefits when both benefits and costs vary, and to minimise costs in order to achieve any given level of benefits (Park 2013). The general framework for any cost-benefit analysis has been graphically summarised in Figure 2.6 below.

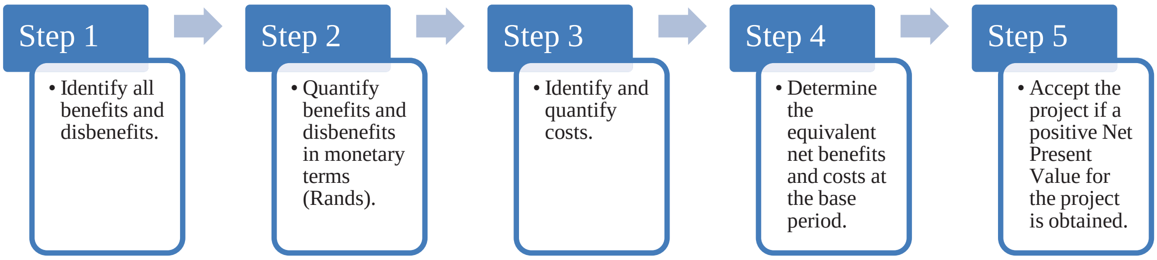


Figure 2.6: The cost-benefit analysis procedure (Park 2013)

Regarding the final decision, the implementation of the Analytic Hierarchy Process: a multi-criteria decision making approach in which the relevant factors affecting the project are arranged in a hierarchic structure (Saaty 1987) was decided upon.

Chapter 3

Research Design and Methodology

3.1 Design

For the completion of this project all the available data was analysed, and additional data recorded through time studies, research and observations, in order to formulate the three most promising layout designs which were then assessed and compared using simulation modelling and an engineering economic analysis to ultimately choose the best layout for an assembly line capable of satisfying the output.

3.2 Methodology

The main deliverables, that is to say the initial proposed layout designs, simulation models, economic analysis and final layout decision, were addressed as follows:

3.2.1 Proposed Layout Designs

The first deliverable for the layout design project was to design three different, practical initial layout designs for the assembly sub-process. The aim of this deliverable was to develop the feasible options for the project to a level of detail that could be reproduced in simulation models and accurately depict the workings of an assembly line. Each of the designs needed to be comprehensive enough in this deliverable to be able to stand alone as the solution to the design problem if selected as the best option. From the literary research already conducted, insight was gained into the layout design methodology used to set up facilities.

It was decided that only the relevant parts of the methodologies, explained in the literature study section of this report, were to be employed in the project in this first deliverable section: the initial layout designs. The first methodology drawn upon was formulated to address requirements analyses in facilities design. The initial stages of the methodology were followed by using the TuksBaja labs to quantify the existing space requirements for the assembly process. Apple's Plant Layout Procedure was then adopted due to its comprehensive coverage of the facilities planning design process (refer to section 2.1.2.). The basic data referred to in Apple's methodology refers, in this instance, to the space requirements (obtained in the previous step) as well as the procurement and assembly times of the TuksBaja assembly line. This however is not an exhaustive list of the required data. The TuksBaja data referred to includes, but is not limited to, the vehicle part/assembly list, manufacturing and procurement times (part arrival times), assembly times, utility costs, labour costs, required tools and space requirements.

Combining this information with existing layout designs used by successful vehicle manufacturing companies and data gathered from time studies, observations and existing data from the TuksBaja team, prospective layout designs were drawn up as per step 15 in Apple's procedure (Figure 2.2).

3.2.2 Simulation Model

Once the initial layout designs were formulated, a simulation model for each design layout was constructed to aid in the decision making process. Simulation models allow for the combination of all the quantifiable data gained so far and to view each layout scenario in its entirety, thus allowing for perspective in terms of the bigger picture. Simulation models also, more importantly, enable the use of part arrival times and assembly (processing) times to run simulation experiments to determine the total time needed for each layout design to meet the production goal of 4000 units.

Modelling methodologies generally refer to continuous and discrete modelling. The project at hand involves a system whose state changes as events occur (e.g. an assembly may leave the assembly line once it has been completed or once all the parts have arrived and been correctly assembled) therefore this system may be classified as a discrete model. The modelling approach undertaken was thus an agent-based modelling approach. In agent-based models there are specific entities (e.g. the operators working on the assembly line) that are governed by a set of rules (e.g. the average time it takes an operator to assemble a particular sub-assembly) and that interact with each other (e.g. once an operator has completed part of a sub-assembly another operator may transport it to the main assembly to be fitted to the vehicle or next sub-assembly).

The simulation software package 'Simio' was chosen for this project. Simio is a well known simulation package that provides a 3D object-based modelling environment which allows the user to fully capture 3D spatial relationships in the system. Simio caters for agent-based modelling and represents the entities and their relationships in 3D in addition to allowing the user to set up 'experiments'. These experiments use the supplied data to provide further information to the user (e.g. considers part arrival times, processing times and possible delays to output the expected completion time of the assembly) and allows the user to change certain variables in order to analyse different possible scenarios. For these reasons this package fell directly in line with this project's needs. Furthermore, Simio runs experiments swiftly, is fairly simple to set up and provides logical and relevant results.

The main goal of this deliverable was to identify which layout would reach the production goal in the least amount of time. A secondary goal was to map out the space requirements of each layout in a 3D model to evaluate each design from an ease-of-use and aesthetics point of view. Each model built on Simio operates on the real times obtained from time studies conducted on the TuksBaja team. The main elements include workers, part arrivals (purchased and manufactured) and assembly times (arrival, departure and processing). Additional important aspects, such as possible delays, were also included so as to create a model that replicates real life operations of an assembly line as accurately as possible. Once each model was set up, experiments to obtain the data to answer the questions pertaining to time and space requirements for each layout was performed.

3.2.3 Economic Analysis

In conjunction with the above mentioned simulation model an economic analysis was incorporated into the decision making process of this project. Generally speaking there are four major types of economic analyses: namely cost analyses, fiscal impact analyses, cost-effectiveness analyses and cost-benefit analyses. The most fitting analysis for this project was the cost-benefit analysis since it, by definition, is a method used for comparing the economic pros and cons of options and in doing so helps to identify the best option to pursue. Cost-benefit analyses also force the user to quantify all costs and benefits (direct and indirect) in order to provide a thorough outlook on each scenario. The main aim of this deliverable was to identify which of the three proposed assembly line layout designs is the most economically feasible. A lesser aim of this deliverable was to also advise the TuksBaja team on the economic practicality of their chosen selling price for Car 2.

Data obtained from the TuksBaja team, as well as industry research, relating to costs was used to perform the cost-benefit analysis. Each of the three layout designs was closely examined and evaluated in terms of their direct and indirect costs and benefits which took account of the tools, a suitable workshop space and set up costs, as well as the monthly running costs which, in itself, incorporated utility costs, wages and salaries, purchasing costs and additional costs resulting from defective parts, errors, etc.

The selling price, predetermined by the TuksBaja team, was then used in addition to these costs to determine the applicable figures for the total capital required, monthly running costs, net present values, etc. Following this, a study of the resulting figures was completed in order to rank the layout designs according to their economic prospects. Using these resulting figures, the TuksBaja team could then be advised as to whether their selling price is financially practical or not and what the recommended commercial price should be if the current price is deemed impractical.

3.2.4 Final Layout Decision

The three deliverables mentioned above coalesced for the final deliverable: the final layout decision. For this crucial decision the analytic hierarchy process (AHP) was used. AHP is a mathematical technique used to organise and analyse complex decisions. It provides a rational platform to weigh alternatives up against each other using decision criteria stated by the user. The goal for this deliverable, and the project as a whole, was to determine which design would be the best for the TuksBaja manufacturing facility assembly line. AHP was thus an ideal technique for this project in the sense that it could be used to select the most appropriate assembly line layout design by comparing the three alternatives (gained from deliverable 1) in terms of their time and space requirements (deliverable 2) and their operational economic standings (deliverable 3).

The structure and ensuing amalgamation of the first three deliverables, as well as the expected inputs for each, can be seen graphically in Figure 3.1 on the following page.

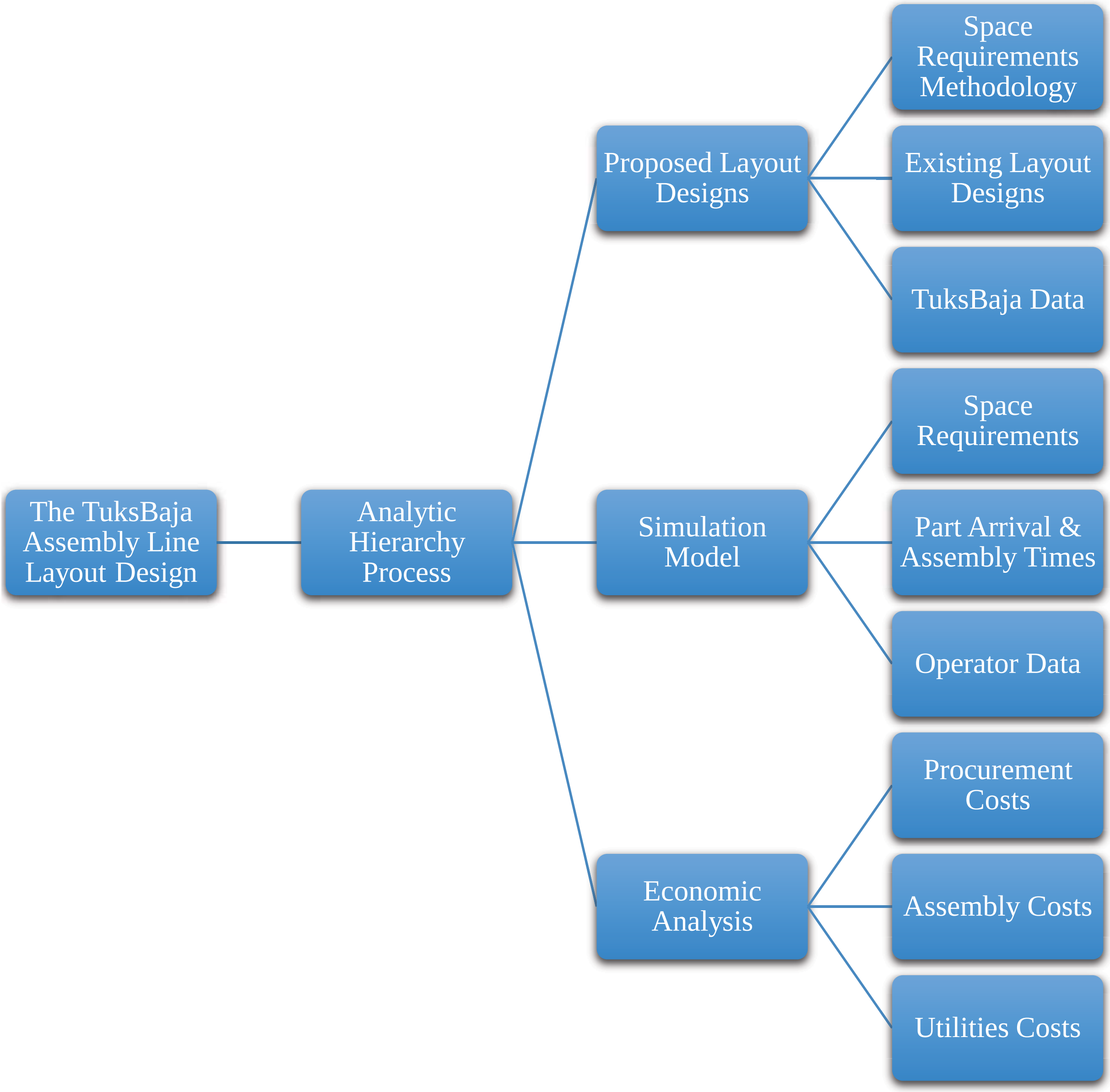


Figure 3.1: Work breakdown structure summarising the project methodology

Chapter 4

Project Implementation

The planning and procedure for the implementation of the project at hand has been detailed extensively in chapter 3. This chapter serves to document the execution of the design of the TuksBaja Production Facility assembly line layout. The first step followed was the data collection step intertwined closely with the understanding of the system. Time was spent analysing the current setup from an industrial engineering point of view and the results were as follows:

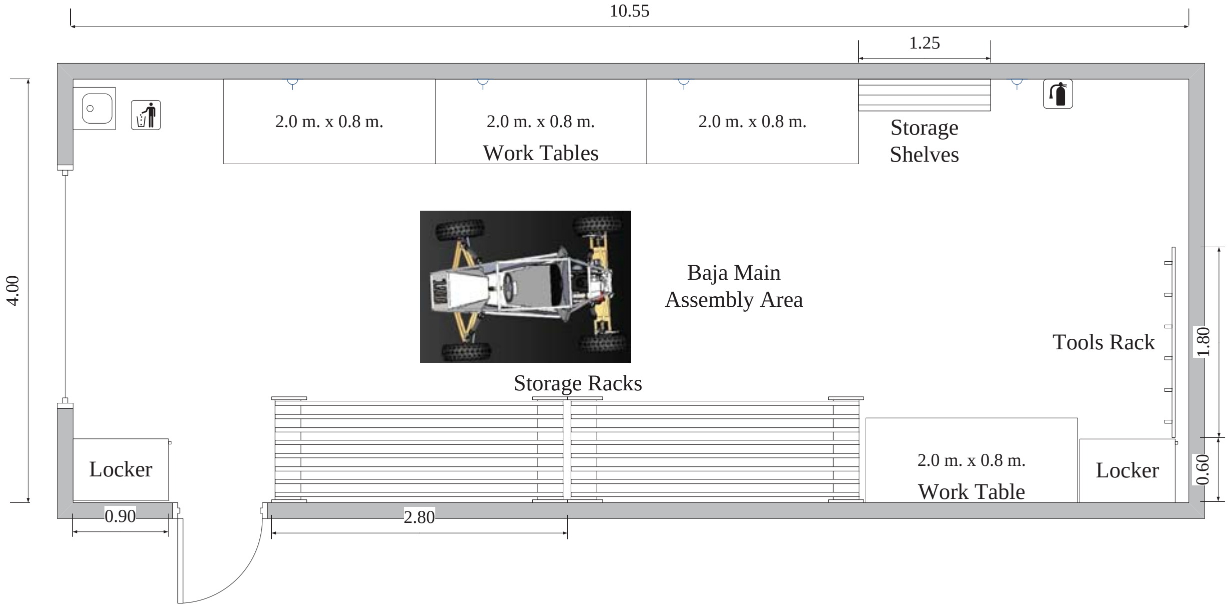


Figure 4.1: The existing layout of the TuksBaja labs

The current setup of the TuksBaja workshop follows an adaptation of the 'fixed materials location' and 'team production' design layouts such that the frame of the vehicle remains in the centre of the workshop and all the sub-assemblies are either assembled elsewhere and then fitted onto the frame or simply fitted directly onto the frame. All movement is performed by the students (operators) who are also entirely responsible for any material handling needs. Available to assist in material handling efforts are two trolleys: one flatbed and one two-wheeled vertical trolley. The existing layout of the

TuksBaja workshop may be seen in Figure 4.1 on the previous page.

The current captain and vice-captain of TuksBaja, Odette Scholtz and Matthew Perry (8 April 2015), were then interviewed to confirm the procurement and assembly times, obtained from previous time studies, for each sub-assembly involved in Car 2. The data, in the form of an adaptation of a networking diagram, has been presented in Figure 4.2 below.

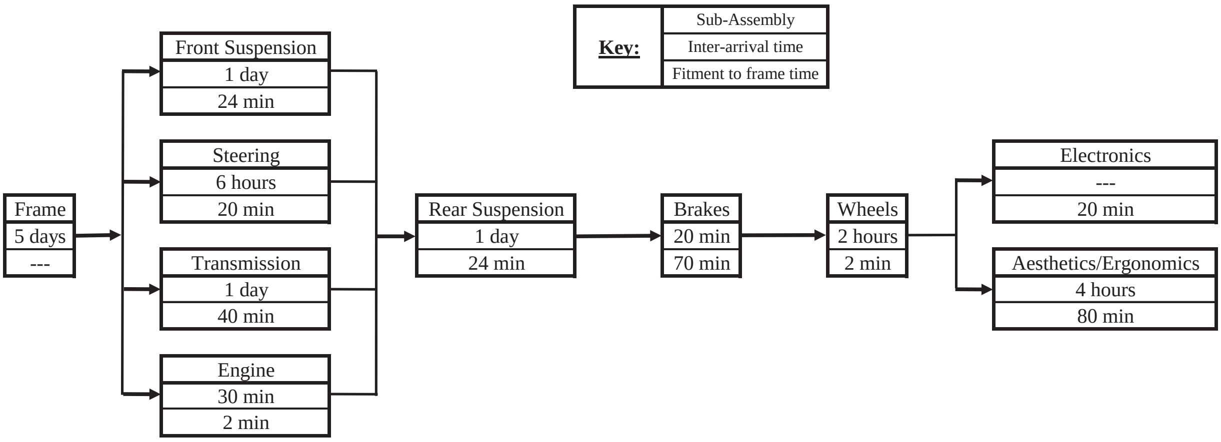


Figure 4.2: An adaptation of a networking diagram showing procurement times and the assembly sequence and corresponding assembly times

As explained in section 1.3, if the assumption is made that South Africa operates on an average of 250 working days per year, and the production demand goal remains fixed at 4000 units per year, it can be concluded that sixteen Car 2 vehicles need to be completed per working day. The critical path on the networking diagram above follows the sequence:

Frame - Transmission - Rear Suspension - Brakes - Wheels - Aesthetics/Ergonomics

This sequence follows the critical path obtained from the assembly times relating to the fitting of each sub-assembly onto the main assembly and the assembly order, shown in Figure 4.2, has been closely followed in all three proposed layouts. The inter-arrival times stated on the networking diagram do not affect the production rate directly but rather the buffer sizes resulting from each sub-assembly station (and thus the work scheduling of each of these sub-stations) and amount of parts on each storage rack at each workstation.

From the critical path it can be seen that one vehicle will take a minimum of 3 hours and 36 minutes to assemble, subject to the full availability of parts. It can thus be estimated that in an ideal scenario of no delays and an uninterrupted flow of parts, the total demand of 4000 vehicles may be met in 14 400 hours. Working on 40 hours a week, or 8 hour days, this then translates to 360 weeks, or 1800 days, in terms of man hours needed to meet the demand. These figures, specifically stated in man hours, apply to the scenario whereby only one vehicle is worked on at a time. In each of the chosen layouts however many cars may be assembled simultaneously. The exact number shall be stated and explained accordingly in each section.

4.1 Proposed Layouts

4.1.1 Team Production Layout

An adaptation of the Team Production Layout is currently being used by the TuksBaja team. This is due to space constraints, suitability in terms of a student-based society and most of all due to the output demand of only one vehicle per season. True to Team Production form the entire production job is carried out by a single team (the TuksBaja team) and the focus is product-orientated.

The Team Production layout designed in this project draws its essence from the original, existing TuksBaja layout. Each workstation has been designed with a main assembly table surrounded by the necessary sub-assembly tables. A storage rack kitted with all the parts needed for a complete Car 2 has been positioned on one end of the workstation and a team of skilled operators has been assigned to each workstation. The operators are responsible for both their sub-assemblies and the fitting of these sub-assemblies onto the main assembly as well as the appropriate quality assurance checks. Only one vehicle may be worked on at a time per workstation and so operators should be skilled in more than just their sub-assembly area in order to assist in other areas when need be.

Due to the non-bulky nature of Car 2's parts the operators have the option of either manually carrying small parts or using trolleys to transport heavier sub-assemblies. Quality control is to be performed throughout each sub-assembly process as well as at the main assembly table. In terms of mass production, the single workstation portrayed in Figure 4.3 below should be repeated a minimum of 8 times over. The logic behind this is that if the demand is sixteen vehicles per day and each workstation is capable of producing one vehicle every 3 hours and 36 minutes then it can be approximated that, in an almost ideal scenario and working with 8 hour days, each workstation can produce two complete vehicles per day and thus 8 workstations are needed.

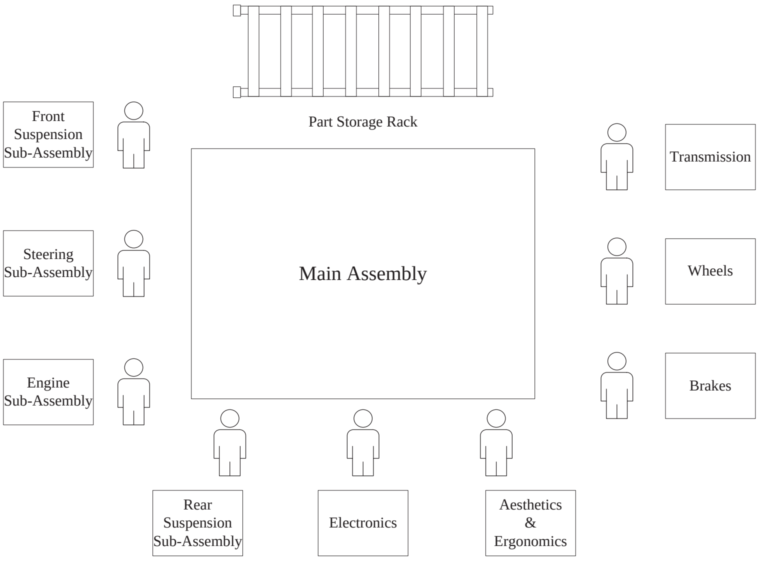


Figure 4.3: The proposed Team Production layout for the TuksBaja assembly line

4.1.2 Modular Assembly Line Layout

As previously mentioned in the literature review, a Modular assembly line layout is a combination of the Tree Flow Pattern and Cellular Manufacturing. This design, historically popular in the automotive industry and thusly selected as one of the prospective designs, increases efficiency by allowing independent sub-processes to be performed simultaneously.

In the Modular layout designed for this project, depicted in Figure 4.4 on the following page, the main assembly line dominates the centre of the facility while smaller, sub-assembly workstations have been positioned on either side of it. This design embodies the typical production line in the way that many vehicles may be present on the main line at a time and consequently be classified as 'work in progress'. Each sub-assembly workstation is to be stocked with the necessary parts for the day on the provided storage racks behind each station before the work day begins or at the end of the previous working day. Each workstation is to have a qualified team of operators dedicated to that station and sub-assembly. These operators will not only perform their assembly work but also perform the applicable quality checks and fitting of their sub-assembly to the main assembly on the main assembly line.

Once again only trolleys are needed in terms of material handling for this design. Overhead cranes are not needed for the assembly process however the actual main line is a conveyor belt. While flat belt conveyors are the conventional choice for the transportation of light to medium weight loads (due to their significant control over loads afforded by the friction between the belt and the object and its ability to successfully navigate inclines and declines) they also prevent smooth flow in operations and often require electricity. Roller conveyors were thus chosen over flat belt conveyors since they may function powered or non-powered. This consideration impacts the economic analysis phase of the project in terms of long term running costs. Non-powered roller conveyors use gravity as well as forces originating from operators to move assemblies along the belt on smaller rollers. Should the load be too heavy (as in the case of Car 2 towards the end of the main line) then certain motorised 'zones' may be implemented wherein only one roller every x number of rollers may be motorised and subsequently used to drive the following driven rollers. In this way power consumption is still minimised.

As depicted in Figure 4.4, on the following page, there also exists a small but vital quality control team at the end of the line to ensure all quality standards have been met and that the best possible Car 2 leaves the line at the end of every assembly cycle. In addition to this, inherent quality control at every stage from every worker is expected. With regard to mass production requirements it can be said that if only one conveyor belt is used and sixteen vehicles need to be completed per 8 hour day then two vehicles need to be completed every hour. While this seems impossible at this point the simulation model is the only way to confirm this hypothesis once all workstations are running and varying numbers of operators are employed. Should this hypothesis prove to be true then a second (and possibly even a third) main line in additional warehouse spaces will have to be considered in order to meet the demand.

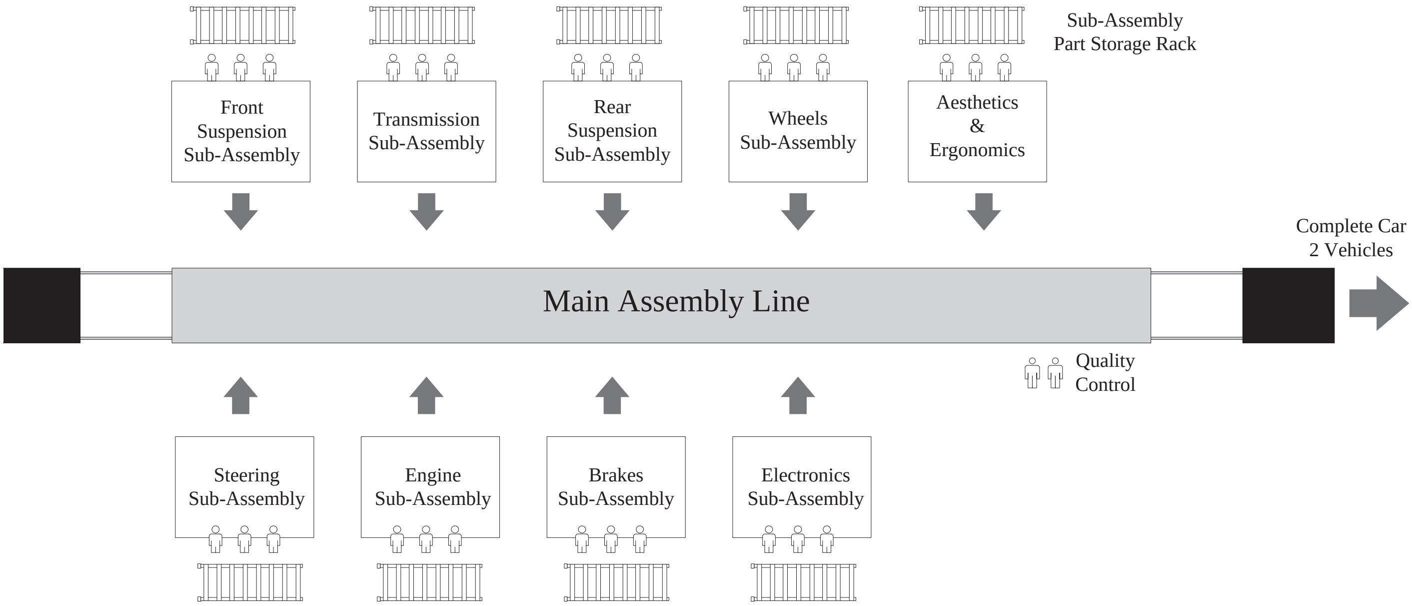


Figure 4.4: The proposed Modular layout for the TuksBaja assembly line

4.1.3 U-shaped Assembly Line Layout

U-shaped process lines stem from an optimisation-based modification of the traditional straight line process line. In this modification the operators have all been situated on the inside of the 'u' shape to allow for and encourage better communication within the process as well as greater visibility/system transparency. This shape also allows for multi-skilled operators to perform a multitude of jobs, thus reducing the number of operators needed.

The U-shaped layout designed for this project focuses on the U-line as the main assembly line in the centre of the facility. The single initial entry on the main line is the frame while the output is the completed Car 2 vehicle. Once again, many vehicles may be present on the main line at once thus a higher work in progress inventory level is maintained for this design. Sub-assembly workstations have been located on the outside of the U-line and each has been designed to operate with their own storage rack complete with all the necessary parts. In this design there are two types of operators. The first type is the sub-assembly workstation teams. Their sole job is to complete their sub-assembly and transport it to the main line. The second type is the operators stationed on the main line. These operators largely remain fixed in their positions and perform the job of fitting the sub-assemblies onto the main assembly.

In terms of material handling, trolleys are needed to transport the sub-assemblies to the main line as well as a conveyor belt which constitutes the main line. As mentioned in section 4.1.2, roller conveyor belts shall be utilised. In terms of mass production, the same principle that applies to the Modular assembly line layout hypothesis applies here. True figures may only be ascertained from the results of the simulation models however once again sixteen vehicles need to be produced per 8 hour day. In this layout design, since there are different (and thus more) operators working on the main line and working at the sub-assembly stations it should result in a higher production rate however this is at the cost of paying more operators and thus an overall higher running cost to be factored in to the economic analysis. Quality control is once again to be performed inherently at every stage as well as at the end of the main line by a small team of independent operators. Figure 4.5 on the following page demonstrates this layout.

4.1.4 Adaptability & Flexibility

When considering the future of the TuksBaja Production Facility one must cater for the possibility of modifications to the current design of the main vehicle as well as for the introduction of completely new vehicles. The Team Production layout is completely independent of the vehicle design and would only require a change in the number of workstation tables surrounding the main table depending on the number of main sub-assemblies of the new design. The Modular assembly line layout and U-shaped layout would also simply require an adjustment in the number of sub-assembly workstations however the U-shaped layout would then also require additional operators on the main line in addition to the extra operators required for the extra workstations. Depending on the nature of the parts and their resulting sub-assemblies, different material handling techniques (and storage methods) may need to be employed such as overhead cranes and/or forklifts. This will also require a third type of operator who specialises in operating the supplementary material handling equipment.

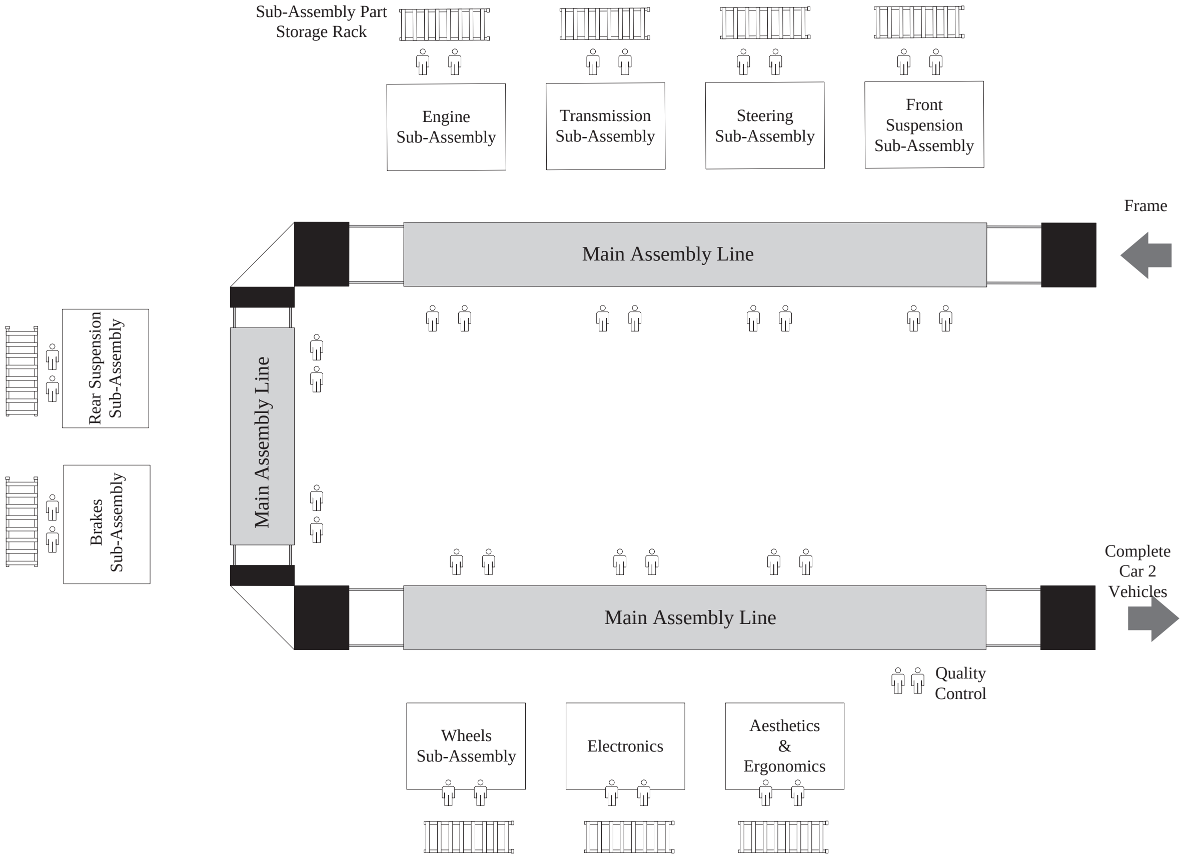


Figure 4.5: The proposed U-shaped layout for the TuksBaja assembly line

4.2 Simulation Modelling

4.2.1 Proposed Layouts' Simio Models

Each of the proposed layout designs for the TuksBaja Production Facility assembly line were simulated using Simio. This entailed superimposing the background information and arrival and assembly times gathered from the existing system onto the layout proposals designed in Section 4.1 and building each model in Simio.

The primary aim of each model, and its corresponding set of experiments, was to determine the minimum number of workers required to meet the production goal of 4000 units per year. To reach this goal the maximum number of workers were first utilised for the majority of experiments and calculations instead focused on determining the maximum production capabilities of each layout. In this way the number of warehouses needed to meet the demand goal was determined. Practically, it was hypothesised that one warehouse for each design would not meet the demand and after running all the experiments in this phase it was confirmed that two warehouses per design will be needed.

For all three layout designs the same space and time constraints were enforced. In terms of warehouse space, a floor area of 28m x 26m was chosen which allows for one U-shaped assembly line (27m x 26m), two Modular assembly lines (each 14m x 24m) or four Team Production layouts (each 13m x 12m). This concept has been demonstrated in the series of figures below. It should be noted that even though multiple layouts for a design may be housed in a single warehouse, each layout is completely independent of the others and so workers, parts, tools, etc. cannot be transferred or shared between layouts.

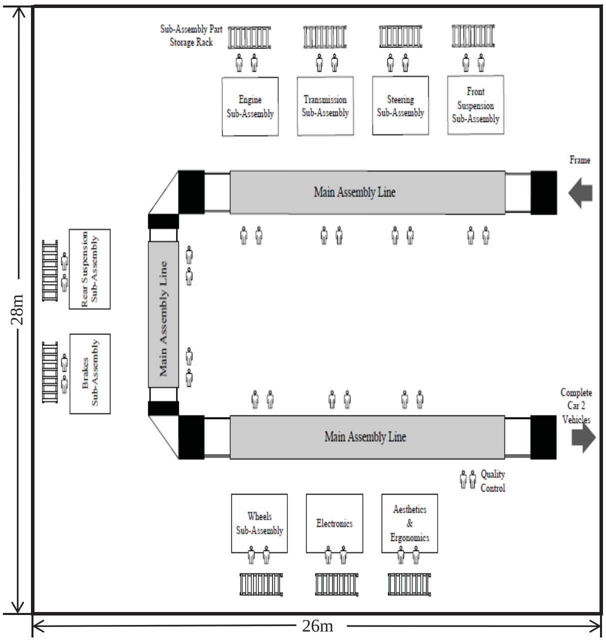


Figure 4.6: The 28m x 26m warehouse will house one 27m x 26m U-shaped layout.

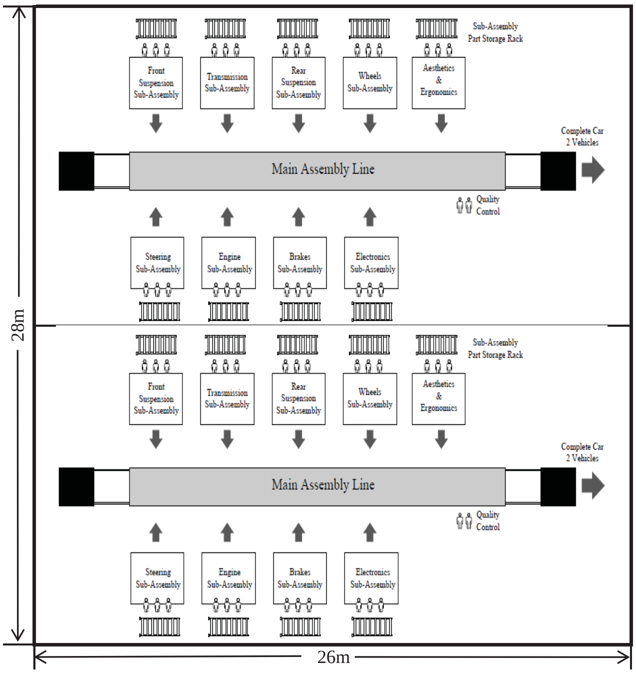


Figure 4.7: The 28m x 26m warehouse will house two 14m x 24m Modular layouts.

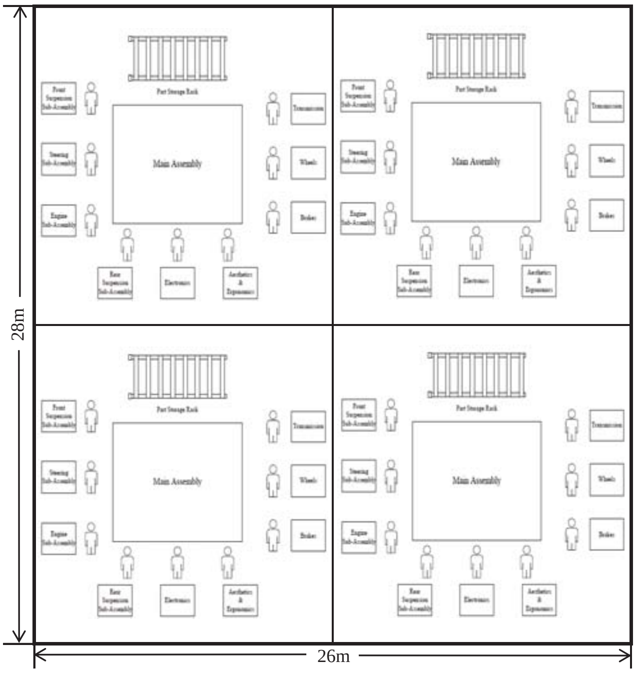


Figure 4.8: The 28m x 26m warehouse will house four 13m x 12m Team Production layouts.

4.2.2 Model Experiments & Results

4.2.2.1 Experiment Design

After each model was built, its ability to successfully and accurately simulate the assigned layout was tested. Thereafter, experiments were designed to investigate the number of Car 2 vehicles that could be assembled per model in the allocated 14 400 hours using the least amount of workers. This was done in two phases.

The first phase focused on determining the maximum output capability of each layout which would in turn determine how many warehouses would be needed in order to meet the demand for that model. For this phase the maximum number of workers for each layout was used so as to thoroughly gain the maximum output potential of each design.

The aim of the experiments in the second phase was to ascertain the minimum number of workers required to meet the maximum production capability determined in phase one, thereby minimising each layout's running costs. In each iteration of each experiment in phase two only the number of workers was varied while the number of completed vehicles and the average total time each vehicle spent in the system was tracked and recorded. One should also remember that each model only simulates a single layout and that, for example, in the case of the Modular layout, two such layouts shall be accommodated in the warehouse and so the resulting outputs shown in the experiments are actually only half of what the warehouse output is expected to be.

For the Modular layout there exists only one type of population of worker, excluding the minor role of 'Quality Control' workers, per sub-assembly for the entire system and each of these sub-populations (each sub-assembly has its own sub-population of workers) was varied to determine their effect on the number of completed vehicles as well as the average time each vehicle spends in the system.

Since the U-shaped and Team Production layouts have two different types of populations (each sub-assembly population as well as the main line/assembly population of workers), more experiment iterations had to be developed in order to comprehensively meet the same goal requirements as the Modular layout.

4.2.2.2 Phase 1 Results

4.2.2.2.1 Modular Model

Table 4.1, on the following page, shows a summary of the results of the initial experiments run on the Modular layout model. A base case of one worker for each sub-assembly sub-population (SA pop), as well as for the quality control population (QC Pop), was chosen however this was done purely for comparative reasons. Having only one worker per sub-assembly is not a feasible solution since practically, at least two workers are needed for most sub-assemblies in order to correctly perform the tasks crucial to the assembly process. This statement has further been supported by the results. Two more types of experiments were then run using two quality control workers and sub-populations of two and ten workers for the sub-assembly populations. These numbers were chosen as two and ten are the minimum and maximum numbers of workers respectively that would be able to work at the same table effectively. Besides the total number of completed vehicles (output), the average time each vehicle spent in the system (TIS) was also recorded for each experiment.

Originally, when the models were designed, optimum batch sizes for the arrival of parts was considered outside the scope of the project and an unlimited supply (no shortages) was assumed however, in terms of running the experiments, this assumption proved impractical. For this reason an ‘Entities per Arrival’ variable had to be factored in although the design of each model remained fundamentally the same. The major difference was that the entities per arrival variable needed to be set for each experiment and within a range that was large enough to mimic the unlimited supply system however small enough that it did not cause the experiment to crash. Several experiments were run testing different batch sizes and those producing the largest complete vehicle output without causing excessive delays in the system have been shown in Table 4.1.

Table 4.1: Table to show the initial results for the Modular layout design model

SA Pop	**QC Pop**	**Entities/Arrival**	**Output (vehicles/year)**	**TIS (hours)**
1	1	1	258,2	129,11
2	2	5	556	2531,63
10	2	6	1565,8	11,16

From Table 4.1 it appears that when one worker, per sub-population, is employed and a batch size of one is used the output is less than when two workers, and a larger batch size, are used however the time that one vehicle spends in the system is much larger for the second scenario. This is due to the fact that when only one entity per arrival is set, during the year long run the system gets starved for parts and so the workers are left idle and production ceases. In the second case, when two workers are used, the time in system increased so dramatically because the workers spent too much time transporting parts around the system instead of sub-assembling them. In case three, where the maximum number of workers are used, the production increased and the time in system decreased to that of a more realistic time since in this scenario there were enough workers to be able to delegate transporting parts to some workers while others concentrated on sub-assembling.

Table 4.2: Table comparing the effect of different batch sizes on the completion of vehicles

Entities/Arrival	**Output (vehicles/year)**	**TIS (hours)**
2	522	19,75
3	783	14,76
4	1044	12,53
5	1304,9	11,50
6	1565,8	11,16
7	138,4	11,23
8	18,3	no output time

The experiments testing different batch sizes maintained the same sub-assembly populations and varied the entities per arrival. An example of the results of one such experiment, performed for the Modular model, may be seen in Table 4.2, above. From these results it was concluded that for the maximum number of workers in the system, the optimal batch size for the arrival of parts for the Modular model would be six full sub-assembly part packs per day. A greater batch size than six resulted in a drastically decreased output. This may be attributed to delays in the system due to workers wasting time transporting extra parts around the system that are not needed for production. In severe cases, such as when eight entities per arrival was used, the experiment returned no output time at all.

4.2.2.2.2 U-shaped Model

Table 4.3, below, shows a summary of the results of the initial experiments run on the U-shaped design model. A base case of one worker for each sub-population, as well as for the quality control and main line populations, was once again chosen. This was followed by similar experiments, varying the batch sizes, or entities per arrival (EpA), as was conducted for the Modular model, which instead enlisted two quality control workers and sub-populations of two and ten workers for the sub-assembly populations and two and five workers for the main line (ML pop) populations respectively.

Table 4.3: Table to show the initial results for the U-shaped layout design model

SA Pop	ML Pop	QC Pop	EpA	Output (vehicles/year)	TIS (hours)
1	1	1	1	260	41,06
2	2	2	5	566	2507,5
10	5	2	9	2345,8	17,42

Since more workers have been designed into this model it can be reasoned that the work load has been distributed over a larger number of man hours and so the resulting greater output was expected. Since production in general moves at a faster pace in this model, a larger batch size was thus required to meet the production demands and not starve the system of parts which would halt production (as is evident in the third experiment).

4.2.2.2.3 Team Production Model

Lastly, Table 4.4 below shows the initial results for the Team Production model. The base case once again featured just one worker stationed at each sub-assembly table and at the main assembly table while the minimum and maximum cases were represented by two and five workers at each station respectively.

Table 4.4: Table to show the initial results for the Team Production layout design model

SA Pop	ML Pop	QC Pop	EpA	Output (vehicles/year)	TIS (hours)
1	1	1	1	203,9	156,7
2	2	2	2	398	2714,3
5	5	2	5	517,4	19,2

The Team Production layout operates in a much more confined environment and so despite the workstations being the same size as the other layouts, the maximum number of workers assigned to a station has been practically restricted to five since only one vehicle is worked on at a time and so the extra workers would either spend their time idle or causing delays by being in the way.

A smaller total output was expected since fewer workers have been assigned to this model and four such layouts of this design are to operate per warehouse. Smaller batch sizes were also necessary due to the slower moving nature of this model and from these results it can be seen that a total of two warehouses would be needed to meet the total annual demand.

Overall the simulation models for phase one recommended that two warehouses would be needed for each layout in order to meet the demand goal and that, per layout, the U-shaped design has the greatest output potential however in terms of using the two standard warehouses for each, the Modular design would meet the production goal the fastest.

4.2.2.3 Phase 2 Results

To minimise costs, in terms of employee wages, the minimum number of workers required to meet the same production outputs from phase one needed to be determined. This was done through a series of experiments for each model that kept all factors constant except for the number of workers in each sub-population. The minimum number of workers required for each layout has been defined as the smallest number set for a worker sub-population that still meets the maximum output established in phase one.

Table 4.5 below shows the production outputs (total vehicles produced per year), and the corresponding average time in system each vehicle would spend, for the Modular model. Sub-populations were varied within the range of one to ten workers (minimum and maximum feasible solutions in terms of the real process) while the quality control sub-population was tested using one, two and three workers. The best (minimum) sub-population figures have been highlighted in green and the results were as follows:

Table 4.5: Table showing the production outputs (total vehicles produced per year), and the corresponding average time in system each vehicle would spend, for the Modular model with the optimum number of workers for each sub-assembly highlighted in green.

	FSusp		Steering		Trans		Engine		RSusp		Brakes		Wheels		Elec		AesthErg	
1	79,2	4158,8	153,9	3962,2	106,4	4117,2	1565,8	12,901	61,5	4340,4	1564,5	18,491	1124,9	1253,4	1565,8	11,739	185,6	3898
2	598,4	2723	781,7	2212,6	713,8	2401,3	1565,9	11,229	560,5	2822,3	1565,9	11,905	1565,9	11,202	1566	11,381	1076,9	1376,7
3	837,9	2046,3	1094,5	1337,1	988,3	1632,1	1565,7	11,17	800,7	2155	1566	11,562	1565,9	11,165	1565,7	11,334	1541,3	86,607
4	1070,5	1401,9	1447,4	346,1	1266,1	855,35	1565,9	11,145	1027,1	1522,6	1565,9	11,391	1565,8	11,238	1566	11,297	1565,5	12,541
5	1313,7	722,23	1564,8	16,121	1539,8	91,632	1565,8	11,164	1255	885,99	1565,9	11,329	1566	11,135	1565,9	11,243	1566	11,493
6	1547,8	70,719	1565,7	12,101	1565,4	14,981	1566	11,145	1480,2	253,03	1566	11,343	1566	11,185	1565,6	11,217	1565,9	11,365
7	1565,2	15,988	1565,7	11,266	1565,9	12,069	1566	11,114	1565	16,528	1566	11,245	1565,7	11,233	1565,9	11,147	1566	11,219
8	1565,7	12,986	1565,8	11,236	1566	11,357	1565,9	11,17	1565,7	13,204	1565,9	11,16	1565,7	11,13	1566	11,2	1565,9	11,26
9	1565,7	11,629	1566	11,206	1565,8	11,229	1565,9	11,183	1565,9	11,633	1565,8	11,268	1566	11,114	1565,9	11,119	1566	11,249
10	1565,8	11,161	1565,8	11,161	1565,8	11,161	1565,8	11,161	1565,8	11,161	1565,8	11,161	1565,8	11,161	1565,8	11,161	1565,8	11,161

As expected, the sub-assemblies that required the most time to complete (suspension, steering and transmission) needed the highest numbers of workers to maintain the maximum output. The task completion times were set as expressions dependent on the number of workers and so the greater the number of workers allocated to a task, the faster the task would be completed. This was however limited by the maximum of ten workers per sub-assembly (a preset constraint) as well as the layout design's maximum output (determined in phase 1). Sub-assemblies such as the engine and electronics only required one worker since sub-assembling these components is such a small and rapid job.

These results were then tested by running another experiment (over the same time, etc.) with all the minimised sub-population figures. The experiment confirmed that with the optimised number of workers the model would still produce the maximum output from phase 1 and so maximum output would be reached with minimum wage expenditure.

The results for the U-shaped and Team Production models were determined in a similar fashion and the resulting numbers of all sub-populations for all three models may be seen in the bar graph in Figure 4.9, below.

It should be noted that for the U-shaped model sub-populations for the sub-assemblies have been varied between one and ten while main line sub-populations have been varied between one and five and quality control between one and three. Also of note is that for the Team Production model sub-assembly sub-populations were varied within the range of one and five workers as was the main assembly population.

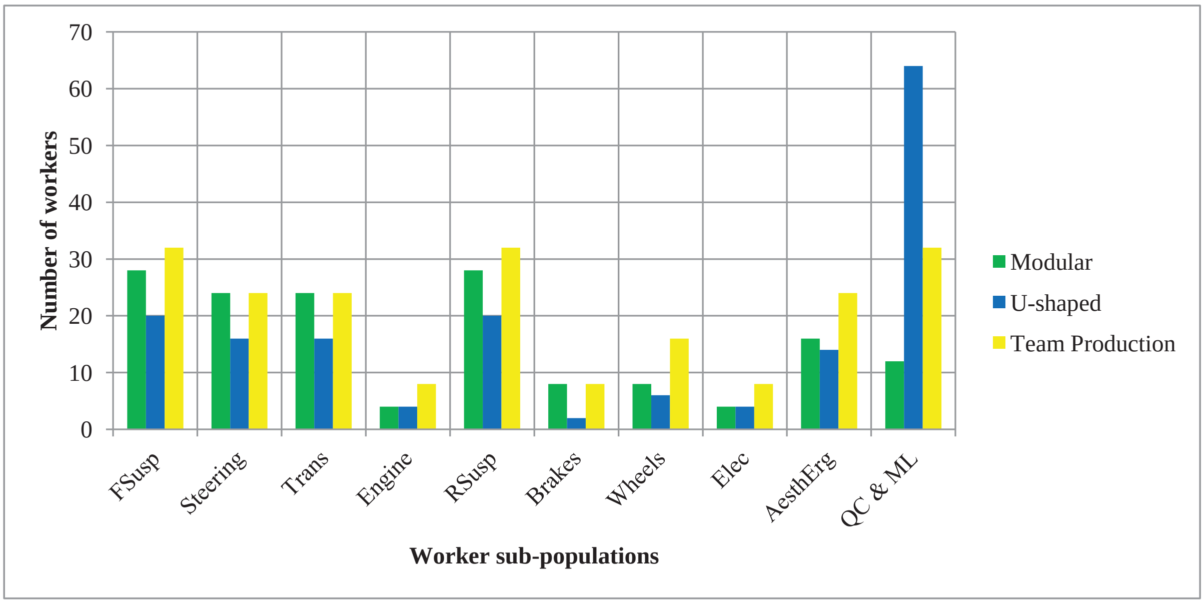


Figure 4.9: Bar Graph illustrating the total number of workers needed per sub-population for two warehouses (to meet the demand)

As is evident from Figure 4.9, similar sub-population totals for each design were required except for the quality control and main line populations. The Modular layout required the fewest numbers of workers in this category since the only workers stationed directly on the main line are the quality control workers. All the other work on the main line is performed by sub-population workers who travel to the main line to fit their sub-assemblies onto the frame and then travel back to their sub-assembly tables.

The Team Production layout required the second most since there is one main assembly table (and eight tables in total for the two warehouses) requiring four workers to fit all the sub-assemblies to the frame while still meeting the maximum production output.

The U-shaped layout appears to require an exceedingly high number of workers in this category however if one reviews the other sub-populations, it appears that the U-shaped layout required the least amount of workers in every other category. This is due to the fact that in comparison with the other two layouts, worker sub-populations have basically been split in two and so the traditional sub-assembly sub-populations are lower than the other layouts however the 'remainder' of their workers have been directly stationed at the main line, along with quality control, which causes the U-shaped figure in this category to be so much higher than the others.

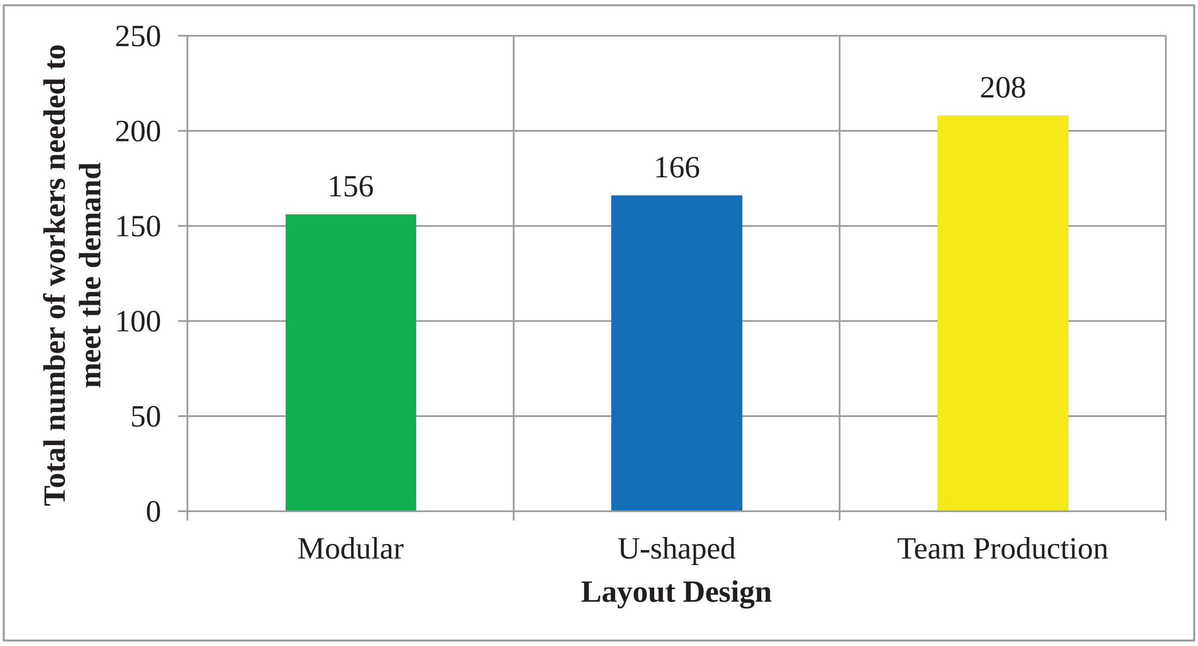


Figure 4.10: Bar Graph illustrating the total number of workers needed for two warehouses (to meet the demand)

Figure 4.10, above, presents a summary of the total number of workers needed to meet the demand for each layout. The Modular layout requires the least amount of workers which could be attributed to its design simplicity while the U-shaped layout requires more workers due to the 'splitting' of each sub-population in order to allow for separate main line teams. The Team Production layout required the most workers in total despite requiring the least amount of workers per layout since a total of eight layouts are needed for two warehouses in comparison to the Modular's four layouts and the U-shaped's two layouts.

4.3 Economic Analysis

A cost-benefit analysis was conducted for each of the three layout designs by examining data obtained from the TuksBaja team, certain figures from the simulation models, as well as industry research, and processing all of this using Microsoft Excel. Each layout was closely examined and evaluated in terms of both direct and indirect costs and benefits and, factoring in depreciation, prime rates and inflation, net present values for each design were calculated. The economic analysis was performed over a five year period.

4.3.1 Costs

When performing net present value calculations in the context of making decisions between alternatives, certain costs that apply equally to all alternatives may be removed from the process. Since all three designs were examined using the same workshop space, rent, insurance, utilities (water and electricity), paint, cleaning, flooring, lighting, ventilation and electrical fitting costs may be omitted from the study.

4.3.1.1 Initial Costs

Initial costs, or capital expenditure, thus includes only the purchasing of tables/workstation benches, tools, trolleys, storage racks and, in the case of the Modular and U-shaped designs, the purchase and installation of the conveyor systems. These costs were determined by requesting quotes from at least three reputable companies for each item and selecting the lowest cost for each. A summary table of the total initial costs for one layout for each design may be seen in Table 4.6, below, while the total capital required to set up two warehouses for each design (and thus meet the demand) may be seen in Table 4.7.

Table 4.6: Table displaying the capital required for one layout of each design (rounded to the nearest thousand Rand)

	Tables	**Tools**	**Trolleys**	**Racks**	**Conveyor**	**Total**
U-shaped	67	152	3	78	17	317
Modular	67	80	3	78	9	236
Team Prod.	96	16	1	9	0	122

Table 4.7: Table displaying the total capital required per design to meet the demand (rounded to the nearest thousand Rand)

	Tables	**Tools**	**Trolleys**	**Racks**	**Conveyor**	**Total**
U-shaped	134	304	7	155	35	635
Modular	267	320	12	311	35	945
Team Prod.	771	128	8	69	0	977

To finance this initial investment it was decided that a loan from the bank, repayable over five years, would be the most suitable option since the capital expenditure, in all three cases, is such a large amount. A sensitivity analysis focusing on the loan repayments over a five year period under different interest rates offered by banks was conducted and the results may be seen in Figure 4.11 below. Prime rate in South Africa is currently 9.5% thus this may be considered as the lowest possible interest rate.

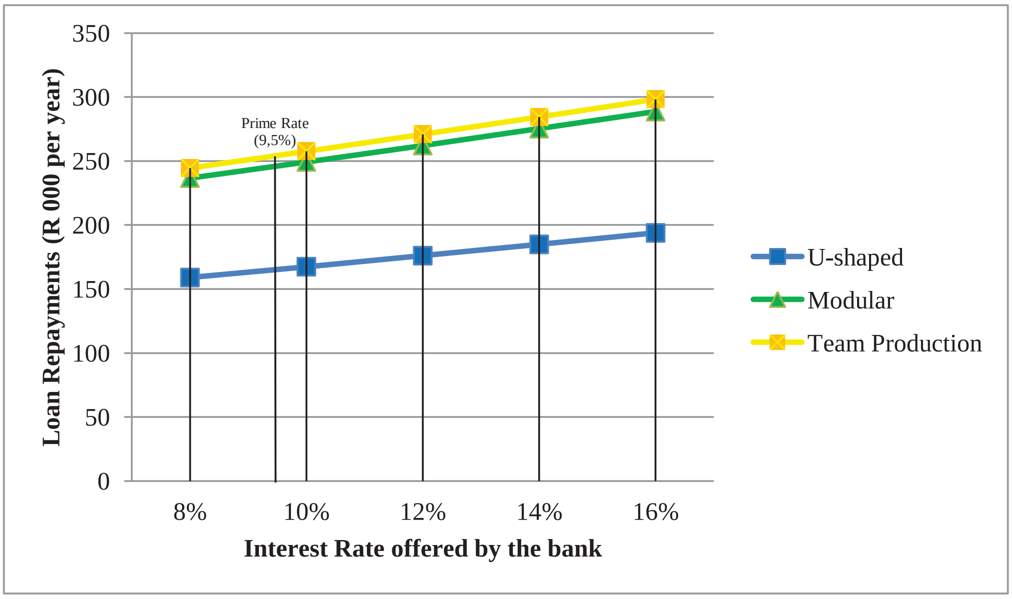


Figure 4.11: Line graph demonstrating the loan repayments required by each design over the range of interest rates offered by the bank

From the graph it can be seen that the loan installments increase by a constant gradient with an increase in the interest rate offered by the bank for all three designs. The U-shaped design has an overall lower loan installment amount due to the fact that the initial investment required for the set up of this design required the least amount of borrowed capital. The Team Production layout required the largest amount of start up capital, and thus exhibits the highest loan repayment amounts on the graph, meaning that it would be the most expensive layout to initiate.

4.3.1.2 Annual Costs

Annual costs comprise of the payment of wages to employees, the replacement of tools and trolleys due to breakages, theft, etc. and the maintenance of the conveyor systems in the Modular and U-shaped designs, as well as the loan repayments (calculated throughout this study, for comparisons, using 14%). These costs have been calculated for the aforementioned two warehouses per design. Summary tables of the annual costs for years one and five may be seen in Tables 4.8 and 4.9 on the following page.

Wages for the employees were determined using MIBCO (Motor Industry Bargaining Council) guidelines. Minimum wage standards, that took effect on 1 September 2015, dictate that for sector one employees (employees involved in the manufacturing and assembly of vehicles) with a first level qualification (Grade 1) the minimum wage be set at R17,82 per hour while employees with a Grade 8 qualification be paid a minimum of R54,95 per hour. For the purposes of this study maximum wage costs were assumed for all three designs and so the R54,95 per hour rate was used in all calculations. The applicable MIBCO document may be viewed in Appendix C. The minimum number of workers was established in phase two of the experiments stage and the results may be seen in Figure 4.10 in section 4.2.2.3.

Table 4.8: Summary of the annual costs for each design in year 1 (rounded to the nearest thousand Rand)

	Wages	**Conveyor**	**Tools, Trolleys**	**Loan**	**Total**
U-shape	137 132	4	16	92	234 724
Modular	128 871	4	17	275	304 300
Team Prod.	165 219	0	7	285	330 730

Table 4.9: Summary of the annual costs for each design in year 5 (rounded to the nearest thousand Rand)

	Wages	**Conveyor**	**Tools, Trolleys**	**Loan**	**Total**
U-shape	162 907	4	19	92	278 825
Modular	153 094	4	21	275	361 444
Team Prod.	196 274	0	8	285	392 841

The cost assigned to replacement of tools and trolleys was calculated by adding 5% of the original cost of each per year while conveyor maintenance was calculated by adding 10% of the original cost per year. The TuksBaja team recommended these estimates based on past experience over the years and calculations they have performed.

4.3.2 Benefits

Excluding the initial investment loan cash flow, only two major benefits came into play in this cost-benefit analysis: the yearly sales figures and the salvage value (SV) of each system after the five year period. The sales cash flow for each design was calculated using the selling price of R150 000 and the given demand of 4000 vehicles per annum, supplied by the TuksBaja team. The salvage value for each was then calculated using the initial investment amount and a range of depreciation rates so that one may consider the range of future possibilities for the investment. This concept has been graphically depicted in Figure 4.12 on the following page.

From the graph it can be seen that all three designs' salvage values decrease geometrically with an increase in the depreciation rate. Both the Modular and Team Production designs display an apparent steeper gradient in comparison with the U-shaped design which translates to them dropping in value faster than the U-shaped design. This can be attributed to the fact that the declining balance method of calculating depreciation was used and that the Modular and Team Production designs started out with higher capital expenditure values so when working with percentages a steeper gradient on the graph for these two designs is to be expected.

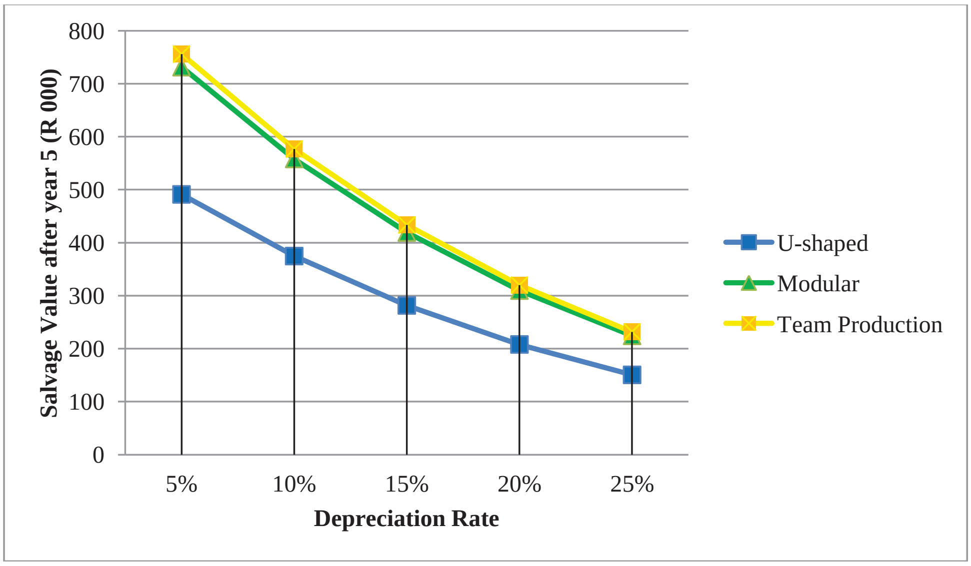


Figure 4.12: Line graph exhibiting the possible salvage values for different annual depreciation rates for each design after a 5 year period

The summary of the benefits breakdown may be seen in Table 4.10 below. The loan amounts and salvage values (calculated throughout this study, for comparisons, using a 10% per annum depreciation rate) are once off benefits while the sales value in the table represents the sales figures for years one and five (factoring in a 4.4% inflation rate).

Table 4.10: Summary of the total benefits for each design (rounded to the nearest thousand Rand)

	Loan (Year 0)	Sales		Salvage Value (Year 5)
		Year 1	Year 5	
U-shaped	635	626 400	744 138	375
Modular	945			558
Team Production	977			577

4.3.3 Results

The results of this cost-benefit analysis have been presented in the form of net present value (NPV) summaries. The net present values were calculated over a range of interest rates and the ensuing table of results may be seen in Table 4.11, on the following page, followed by the sensitivity analysis graph in Figure 4.13.

A depreciation rate of 10% was chosen for the salvage values and an interest rate of 14% for the loan repayments. While net present values for all three alternatives are positive, and thus appear promising, it should be remembered with caution that the scope of this project excludes all processes before the assembly line and so a full net present value study on the TuksBaja Production Facility as a whole would have to include part purchasing costs, manufacturing costs, etc. This will then result in the decrease of all net present value figures. Since these expenses are equal for every proposed design, as previously mentioned, their effect on the net present values have been omitted.

Table 4.11: Net Present Values (rounded to the nearest million Rand) for each design over different interest rates after a five year period

Layout	**10%**	**15%**	**20%**	**25%**	**30%**
U-shape	2 009	1 770	1 573	1 410	1 273
Modular	2 043	1 799	1 600	1 434	1 294
Team Prod.	1 893	1 668	1 483	1 329	1 199

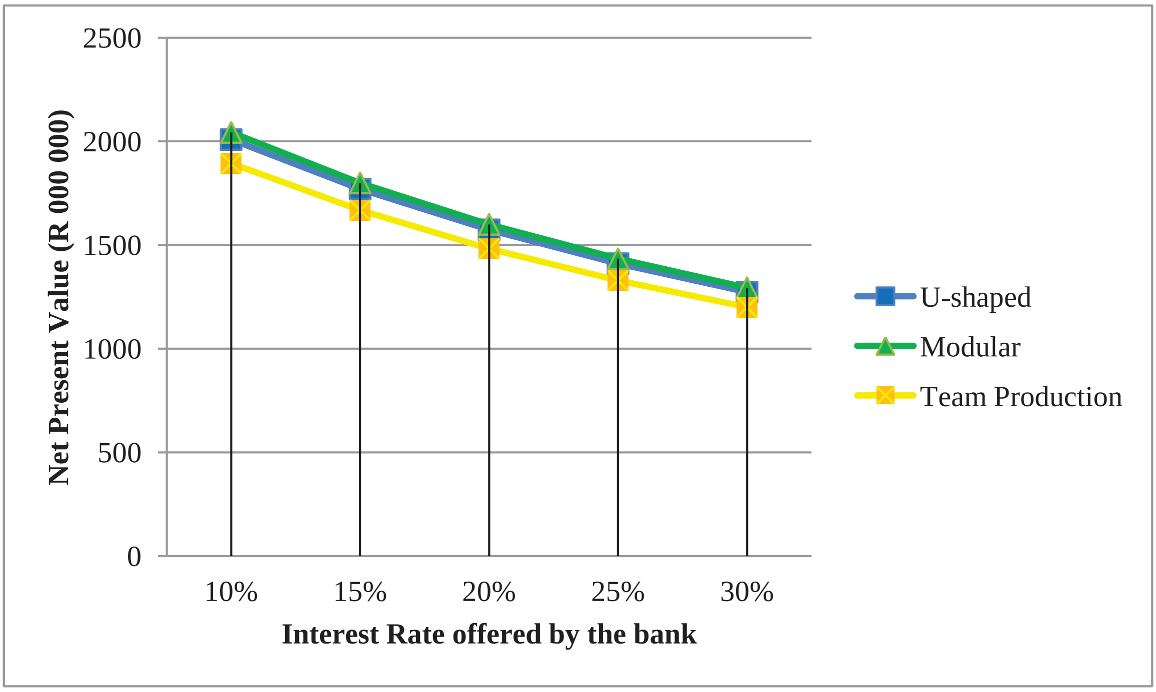


Figure 4.13: Line graph displaying the net present values for each design over different interest rates and after a five year period

In Figure 4.13 the differences between the U-shaped and Modular curves are almost negligible, as is supported by the values in Table 4.11. The Team Production curve exhibits consistently lower net present values than the other two layouts and so it can be concluded from the economic analysis that over the initial five year period the Modular layout proves the most financially suitable option (marginally besting the U-shaped design) since it provides the highest positive net present value.

4.4 Final Decision

The analytic hierarchy process (AHP) was used in the final decision making process of this project as the final decision was a multi-criteria decision. AHP involves assigning weights to each criterion, depending on their importance in relation to each other, followed by a similar process conducted on each option (in this case layout design) with regard to each criterion. These relative weights can then be used, in conjunction with the criteria weights, in equations to determine which option has the highest score, and by extension, is the best option. The weights are assigned using a scale from one to nine where one means the objectives are of equal importance and nine means that the one objective is absolutely more important than the other.

From the simulation modelling and economic analysis stages it was concluded that in terms of meeting the production goal, the Modular design does so the fastest and economically speaking it has the greatest potential, however only marginally. Since the primary objective of each design was to meet the production goal, a higher weighting was placed on this criterion (time, "T") in the analytic hierarchy process. The differences in the net present values of the three designs was very small (in the context of their total amounts) however this criterion (cost, "C") received the second largest weighting followed by the flexibility and suitability for mass production of each design ("F") and lastly TuksBaja's preference ("P"). The designated weights have been illustrated in Table 4.12 below.

Table 4.12: Table illustrating the weights assigned to the criteria used in the analytic hierarchy process

	Time	**Cost**	**Flexibility**	**Preference**
Time	1	4	5	7
Cost	$1/4$	1	3	4
Flexibility	$1/5$	$1/3$	1	2
Preference	$1/7$	$1/4$	$1/2$	1

After normalising these weights in a separate matrix the resulting criteria weights were as follows:

$$\begin{aligned} w_{\mathrm{T}} &= 0.593 \\ w_{\mathrm{C}} &= 0.235 \\ w_{\mathrm{F}} &= 0.109 \\ w_{\mathrm{P}} &= 0.065 \end{aligned}$$

For each of the criteria the relative weights for each layout may be seen in their respective tables below. After normalising these weights in separate matrices the resulting criteria dependent weights for each layout (Modular: “M”, U-shaped: “U”, Team Production: “T”) follow after their corresponding table:

Table 4.13: Table illustrating the layout weights relative to time

	Modular	**U-shaped**	**Team Prod.**
Modular	1	3	5
U-shaped	$1/3$	1	3
Team Prod.	$1/5$	$1/3$	1

$$w_{\mathrm{M/T}} = 0.633$$
$$w_{\mathrm{U/T}} = 0.260$$
$$w_{\mathrm{T/T}} = 0.106$$

Table 4.14: Table illustrating the layout weights relative to cost

	Modular	**U-shaped**	**Team Prod.**
Modular	1	2	3
U-shaped	$1/2$	1	2
Team Prod.	$1/3$	$1/2$	1

$$w_{\mathrm{M/C}} = 0.539$$
$$w_{\mathrm{U/C}} = 0.297$$
$$w_{\mathrm{T/C}} = 0.164$$

Table 4.15: Table illustrating the layout weights relative to flexibility and suitability

	Modular	**U-shaped**	**Team Prod.**
Modular	1	$1/2$	4
U-shaped	2	1	5
Team Prod.	$1/4$	$1/5$	1

$$w_{\mathrm{M/F}} = 0.334$$
$$w_{\mathrm{U/F}} = 0.568$$
$$w_{\mathrm{T/F}} = 0.098$$

Table 4.16: Table illustrating the layout weights relative to preference

	Modular	**U-shaped**	**Team Prod.**
Modular	1	2	3
U-shaped	$^1/_2$	1	2
Team Prod.	$^1/_3$	$^1/_2$	1

$$\begin{aligned} w_{\mathrm{M/P}} &= 0.539 \\ w_{\mathrm{U/P}} &= 0.297 \\ w_{\mathrm{T/P}} &= 0.164 \end{aligned}$$

From these weights the scores for each layout were calculated and the equations may be seen below:

Modular score:

$$= w_{\mathrm{T}} w_{\mathrm{M/T}} + w_{\mathrm{C}} w_{\mathrm{M/C}} + w_{\mathrm{F}} w_{\mathrm{M/F}} + w_{\mathrm{P}} w_{\mathrm{M/P}}$$

$$= (0.593)(0.633) + (0.235)(0.539) + (0.109)(0.334) + (0.065)(0.539)$$

$$= 0.57348 \approx 0.57$$

U-shaped score:

$$= w_{\mathrm{T}} w_{\mathrm{U/T}} + w_{\mathrm{C}} w_{\mathrm{U/C}} + w_{\mathrm{F}} w_{\mathrm{U/F}} + w_{\mathrm{P}} w_{\mathrm{U/P}}$$

$$= (0.593)(0.260) + (0.235)(0.297) + (0.109)(0.568) + (0.065)(0.297)$$

$$= 0.30519 \approx 0.31$$

Team Production score:

$$= w_{\mathrm{T}} w_{\mathrm{T/T}} + w_{\mathrm{C}} w_{\mathrm{T/C}} + w_{\mathrm{F}} w_{\mathrm{T/F}} + w_{\mathrm{P}} w_{\mathrm{T/P}}$$

$$= (0.593)(0.106) + (0.235)(0.164) + (0.109)(0.098) + (0.065)(0.164)$$

$$= 0.12274 \approx 0.12$$

From these results it can be concluded that the Modular layout would be most suitable for implementation as an assembly line at the TuksBaja Production Facility since it scored the highest in the Analytic Hierarchy Process and is thus the best choice.

4.5 Further Implementation

4.5.1 Verification & Validation

Verification and validation is vital in the end stages of a project and its life cycle. Since verification checks whether the solution has met the internally set specifications, and validation checks whether the customer's needs have been met, the combined process thus ensures that the seemingly successful solution is in fact successful through clarifying its aptness in terms of both internal and external requirements.

The need addressed in this project centered around designing and selecting an assembly line layout capable of producing 4000 TuksBaja vehicles in a year at the lowest possible cost. The solution selected was that of a Modular assembly line customised to TuksBaja's specific needs.

The internal specifications were designed around the external specifications set by the TuksBaja team. The critical need addressed was the ability of the layout to meet the demand in the designated time allocation while the secondary aim was to meet this demand at the lowest possible cost. Subsidiary requirements included selecting a model that was suitable for mass production, flexible enough to accommodate design changes in the product and lastly a model that was aesthetically appealing to the TuksBaja team. Since the internal and external requirements were so intricately entwined, the meeting of the one would ensure the meeting of the other.

The Modular layout was tested in the simulation modelling phase and successfully met the demand in the allocated time, and faster than the other two models. According to the economic analysis, the Modular layout also displayed the highest net present value, despite it being only marginally so, thus demonstrating its economic feasibility. The Modular layout is traditionally the mass production layout of choice for the automotive industry and is consequently not only fit for mass production but also flexible enough to adapt to product changes (as was discussed in section 4.1.4). The TuksBaja team was consulted once again to view each design and rank the three layouts according to their personal preferences. The Modular layout was once again deemed the best layout in this category and so by these verifications and validations it can be concluded that the Modular layout successfully meets the project's needs and is therefore an effective solution.

4.5.2 Safety Analysis

Safety in the workplace is of the utmost importance and as a result the Modular layout incorporates a multitude of safety precautions and considerations into its design and implementation. These safety efforts may be categorised into those concentrated on staff and those concentrated on the working environment.

Staff safety may be maximised through the issuance of PPE (personal protective equipment) such as safety goggles, heavy duty gloves, etc. required for the assembly processes as well as the setting up of first aid stations along every line (each Modular layout may be viewed as a line). Every line manager should be OHS (Occupational Health and Safety) certified and should remind workers to not only work responsibly but also to wear their PPE. All workers should be encouraged to obtain their level one first aid qualification certificates and the company may even set up annual workshops to encourage this.

The working environment should be fitted with the correct ventilation system as well as a fire/hazard alarm system that uses both visual and audio alerts. All exits should be clearly marked and floors should be painted appropriately (green denotes walkways, yellow indicates caution, etc.). Safety signs should be a regular feature on walls reminding staff of general safety procedures and all machinery/equipment should be placed on a preventative maintenance schedule in order to avoid accidents occurring due to old/faulty equipment. The factoring in of ergonomics in the workplace helps reduce potential safety issues and so non-slip, heavy duty work mats should be fitted in all standing work areas. In addition to their non-slip safety efforts, these work mats have been proven to reduce fatigue and joint problems in workers and thus help create a more productive working environment.

Regular safety inspections should be conducted and, to thoroughly ensure safety in the workplace, a safety auditing company, such as locally based SGS who perform both risk assessments and management services as well as preventative planning, may be hired.

4.5.3 Environmental Analysis

Environmental awareness and incorporation into company plans has become a non-negotiable necessity in today's business world. The Modular layout makes use of simple but effective tools in reducing its carbon footprint and supporting sustainable development. The conveyor system used in each Modular layout is non-motorised resulting in electric tools and lighting being the only consumers of electricity. Energy saving industrial globes will be used however each warehouse will also be built with north-facing windows which allows for each warehouse to receive maximum amounts of sunlight (natural light) throughout the year since South Africa is in the Southern Hemisphere.

The work mats to be used may be purchased from a company that manufactures them from recycled materials. All workers may also be frequently encouraged to save electricity and water wherever they can, both in the workplace and in their homes, through the use of signs next to power points and in bathrooms.

4.5.4 Recommendations for Future Iterations

Future iterations of this project may be performed in order to gain a more comprehensive understanding of the problem in terms of a larger project scope. An example of this would be to place focus on the batch sizes for the arrival of parts into the system. An in-depth EOQ (economic order quantity) model could be developed which would determine the the optimum order quantity (batch size) that would minimise inventory holding costs and ordering costs. The model could be set up to include stock shortages as well as incorporate the use of safety stock. Queuing theory could be used in future iterations since buffer capacities were excluded from the scope of this project however remain vital in the functioning of engineering systems. More research could also be done on JIT (Just-In-Time) manufacturing to further reduce excess inventory and possibly speed up production. Lastly, focus could be placed on all processes at the TuksBaja Production Facility (e.g. manufacturing) or even the supply chain as a whole.

Chapter 5

Conclusion

The TuksBaja Production Facility Assembly Line Project has been completed in 4 main deliverable stages in order to successfully design and select an assembly line capable of producing 4000 Car 2 vehicles per year under the most economical circumstances.

The three layout designs, decided upon after extensive research, were the Team Production layout, Modular layout and U-shaped layout. The requirements and advantages of each were presented as well as the customised versions of each suited to the TuksBaja project. Provisions for the future of the TuksBaja Production Facility were also addressed in terms of each layout's adaptability and flexibility.

This was then followed by the fabrication and analysis of the simulation models in tandem with the economic analysis, which presented its results in the form of net present value summaries. The simulation models and economic analysis endorsed the Modular design since it met the production goal the most efficiently and since it exhibited the highest positive net present value.

The final decision was made through the use of the Analytic Hierarchy Process and the Modular design was named the best option for the TuksBaja Production Facility assembly line. Further notes on the implementation of the Modular layout were provided as well as a a brief verification and validation summary followed by a few suggestions for future iterations of this project.

Now that the best layout has been selected, with all the appropriate substantiations, the TuksBaja team will be informed of the potential of their Car 2 vehicle and the results may also be used to contribute to the successes of the team in the annual SAE Baja competition. Their existing sales price was deemed profitable, according to the economic analysis, and the mass production potential of Car 2, detailed in this report, may be included in TuksBaja's competition sales presentation. It should be noted that the methodology from this study may be further extended to other vehicle assembly lines (or any similar assembly line) to either design and set up new facilities or optimise and improve existing ones.

Chapter 6

References

Bozarth, C, Vilarinho, PM 2006. Analyzing the Impact of Space Utilization and Production Planning on Plant Space Requirements - A Case Study and Methodology. International Journal of Industrial Engineering, 13(1), 81-89.

Teresko, J, 2002. Strategic Design: Building the World's Next Plants. Industry Week, 251(4), 22-27.

Destefani, J, 2003. Lean by Design and by Necessity. Manufacturing Engineering, 131(3), 59-63.
Apple, J.M, 1977. Plant Layout and Material Handling. 3rd ed. New York: John Wiley.

Reed, R, 1961. Plant Layout: Factors, Principles and Techniques. Richard D. Irwin, (2).

Muther, R, 1973. Systematic Layout Planning. 2nd ed. Boston: Cahner's Books.

Tompkins, J, 2010. Facilities Planning. 4th ed. United States of America: John Wiley & Sons Inc.

Miltenburg, J, 2000. U-shaped production lines: A review of theory and practice. International Journal of Production Economics, 70(1), 201-214.

Fredriksson, P, 2006. Operations and logistics issues in modular assembly processes: cases from the automotive sector. Journal of Manufacturing Technology Management, 17(2), 168-186.

Saaty, RW, 1987. The Analytic Hierarchy Process - What it is and how it is used. Math Modelling, 9(4), 161-176.

Park, CS, 2013. Fundamentals of Engineering Economics. 3rd ed. Essex: Pearson Education Limited.

Appendix B

Car 2 Information Table

Sub-Assembly	Part Purchased	Work performed	
		In-House	Outsourced
Frame			
Primary members			x
Secondary members			x
Wheels			
Tyres	x		
Rims	x		
Hubs		x	
Front Suspension			
Dampers		x	
A-Arms		x	
Bushes		x	
Rod ends		x	
Shaft		x	
Uprights		x	
Booties	x		
Rear Suspension			
Dampers		x	
H-arms		x	
Dog legs		x	
Booties	x		
Steering			
Steering wheel	x		
Steering box		x	
Rack		x	
Steering column		x	
Pinion		x	
Booties	x		
Tie rods		x	
Rod ends	x		
Universal joint	x		
Brakes			
Brake discs		x	
Calipers	x		
Brake pads	x		
Brake lines	x		
Master cylinders	x		
Brake reservoirs	x		
Bias bar		x	
Brake pedal		x	

Sub-Assembly	Part Purchased	Work performed	
		In-House	Outsourced
Transmission			
CVT (primary & secondary)	x		
CVT cover	x		
Hub reductions		x	
HPD pulleys		x	
Belt box		x	
CV joints	x		
Driveshaft	x		
CVT belt	x		
Electronics			
Kill switch	x		
Brake light	x		
Wiring	x		
Battery	x		
Pressure sensors	x		
Aesthetics/Ergonomics			
Seat belts	x		
Seat	x		
Head rest		x	
Fire extinguishers	x		
Fire extinguisher brackets	x		
Firewall		x	
Panels		x	
Numbering		x	
Belly pan		x	
Stickers			x
Engine			
Engine	x		
Fuel tank	x		
Drip tray		x	
Governor box		x	
Throttle cable	x		
Accelerator pedal		x	
Additional			
Nuts	x		
Bearings	x		
Bolts	x		
Washers	x		

Appendix C

MIBCO document

275 Kent Avenue
Ferndale
Randburg
2194
Tel: 0861664226
Fax: 011 369 7600
LRA2/6/6/1

CIRCULAR

MIBCO

NO: **12/2015**

DATED: **12 August 2015**

TO ALL PARTICIPANTS IN THE MOTOR INDUSTRY

2015/2016 PRESCRIBED MINIMUM & GUARANTEED WAGES INCREASES

The new minimum wage rates and guaranteed wage increases for the period ending 31 August 2016, based on the Main Collective Agreement for the Motor Industry (Govt. Gazette No. 37508) Govt. Notice No. R10166 dated 04 April 2014, will come into **effect on Tuesday 01 September 2015** and shall remain in effect for the period ending 31 August 2016.

Hereunder please see the summary of the new **minimum wage rates and guaranteed wage increases ending 31 August 2016.**

INDUSTRY SECTOR CLASSIFICATION - CLAUSE 2: DEFINITIONS

“**Sector 1"** means “manufacturing” establishments i.e. vehicle body builders; trailers and caravan manufacturing and warranty repairs; vehicle components and accessories, fibreglass component manufacturing; repairs and sales.

“**Sector 2"** means “re-manufacturing” (production) establishments i.e. component re-manufacturing; brake, clutch and radiator re-manufacturing; drive-train re-manufacturing and steering re-manufacturing.

“**Sector 3"** means “re-conditioning” establishments i.e. automotive engineering; fuel injection/diesel pumps; gearbox/transmission; turbochargers and spring-smiths.

“**Sector 4"** means “service and repair” establishments i.e. motorcycle sales and repairs; battery sales and repairs; tyre sales, repairs and wheel alignment; tyre re-treading; exhaust, tow-bar and shock-absorber fitting; radio, alarm and immobilizer fitting; sunroof fitting; air-conditioning fitting; body repairs; upholstering and motor trimming; auto electrical repairs; auto valet and steam cleaning; prop-shafts and CV joints repairs; motor plastic component repairs; glass fitting; carburettor sales and repairs; drive train fitting and repairs; steering fitters and repairs; motor vehicles bus, truck and tractor repairs.

"**Sector 5**" means "fuel dealers, service stations and related" establishments.

"**Sector 6"** means "dealers sales and distribution establishments" i.e. used motor vehicle, bus truck and tractor sales and repairs; franchised motor vehicle, bus, truck, tractor, and parts sales and repairs; caravan sales and repairs and agricultural equipment sales and repairs.

"**Sector 7"** means "automotive parts, accessories, equipment and tool" establishments i.e. motor parts, accessories, equipment and tools; auto-breakers and used parts dealers.

ACTUAL / GUARANTEED WAGE EXEMPTION APPLICATIONS

Individual employers seeking exemption to pay a lesser actual wage increase and / or a guaranteed increase or to be exempted from paying such, must do so on a Wage Exemption Application form which is obtainable from their local MIBCO Regional Office or website; www.mibco.org.za . Such application must be lodged no later than 21 days from 01 September 2015 to the local MIBCO Regional Office either by hand delivery, registered mail, facsimile or E-mail in the prescribed format with the following supportive documentation attached:

- Formal financial information;
- Written motivation; and
- Detail and proof of the consultative process between the employer, employee and relevant MIBCO Trade Unions.

For further assistance please contact your local MIBCO Regional Office as per the contact detail on the MIBCO website www.mibco.org.za

---o0o---

DIVISION C, CHAPTER 1 - CLAUSE 3 - WAGES

WAGE SCHEDULE : MINIMUM WAGES - 1 SEPTEMBER 2015

Class of employee	**CHAPTER 1**				**CHAPTER 1**				**CHAPTER 1**	
	SECTOR 4,5 & 7 ONLY				**SECTOR 6 ONLY**				**Guaranteed Increases°**	
	Area A		**Other Areas**		**Area A**		**Other Areas**		**All Areas**	
	P W	P H	P W	P H	P W	P H	P W	P H	P W	P H
Grade 1	R	R	R	R	R	R	R	R	R	R
Forecourt Attendant	1 023.67	22.75	1 023.67	22.75					84.60	1.88
Parking Garage Attendant	614.25	13.65	614.25	13.65					45.45	1.01
Cashier	1 123.24	24.96	1 086.30	24.14					59.40	1.32
Char (Sector 5)*	836.79	18.60	836.79	18.60					67.95	1.51
Char	801.90	17.82	801.90	17.82	839.70	18.66	834.30	18.54	79.65	1.77
Grade 2	1 076.85	23.93	1 050.30	23.34	1 125.90	25.02	1 080.00	24.00	92.70	2.06
Grade 3	1 165.50	25.90	1 165.50	25.90	1 208.70	26.86	1 208.70	26.86	86.40	1.92
Grade 4	1 273.05	28.29	1 273.05	28.29	1 319.40	29.32	1 319.40	29.32	94.50	2.10
Grade 5	1 419.30	31.54	1 419.30	31.54	1 463.40	32.52	1 463.40	32.52	105.30	2.34
Grade 6	1 705.50	37.90	1 705.50	37.90	1 743.30	38.74	1 743.30	38.74	126.45	2.81
Class of Employees	**All Areas**				**All Areas**				**All Areas**	
	P W		**P H**		**P W**		**P H**		**PW**	**PH**
Grade 7	2 124.00		47.20		2 149.20		47.76		157.50	3.50
Grade 8	2 248.20		53.96		2 455.20		54.56		180.00	4.00
Watchman	981.04		no hourly rate		1 016.14		no hourly rate		75.67	no hourly rate
APPRENTICES	**ALL AREAS**				**LEARNERS**		**ALL AREAS**		**° Not Applicable to**	
	ALL CHAPTERS						**ALL CHAPTERS**		**Sector 6 Establishments**	
							NQF LEARNERSHIPS		**CBMT**	
3 YEAR TRADE	**P W**		**P H**				**PW**	**PH**	**PW**	**PH**
First year	1220.85		27.13		Level 1		1220.85	27.13	1164.15	25.87
Second year	1513.80		33.64		Level 2		1339.20	29.76	1453.50	32.30
Third year	1860.65		41.35		Level 3		1513.80	33.64	1747.35	38.83
					Level 4		1860.75	41.35	2034.00	45.20
4 YEAR TRADE										
First year	1220.85		27.13							
Second year	1339.20		29.76							
Third year	1513.80		33.64							
Fourth year	1860.75		41.35							

*Guaranteed increases as prescribed for Chars in Sector 5 only.

Sector 5 Wages are subject to the profit margin adjustment to be determined by the Depratment of Minerals & Energy.

DIVISION C, CHAPTER II - V : CLAUSE 3 - WAGES

WAGE SCHEDULE : MINIMUM WAGES - EFFECTIVE DATE 1 SEPTEMBER 2015

Class of Employee	CHAPTER 2		CHAPTER 3*		CHAPTER 4				CHAPTER 5	
	SECTOR 1		SECTOR 1		SECTOR 3				SECTOR 2	
	All Areas		All Areas		Area A		Other Areas		All Areas	
	P W	P H	P W	P H	P W	P H	P W	P H	P W	P H
	R	R	R	R	R	R	R	R	R	R
Grade 1	801.90	17.82	833.40	18.52	801.90	17.82	801.90	17.82	801.90	17.82
Grade 2	1 076.85	23.93	1097.55	24.39	1 076.85	23.93	1 076.85	23.93	1 076.85	23.93
Grade 3	1 165.50	25.90	1187.10	26.38	1 165.50	25.90	1 165.50	25.90	1 165.50	25.90
Grade 4	-	-	1296.45	28.81	1 273.05	28.29	1 273.05	28.29	1 273.05	28.29
Grade 5	1 419.30	31.54	1446.30	32.14	1 419.30	31.54	1 419.30	31.54	1 419.30	31.54
Grade 6	1 705.50	37.90	1735.20	38.56	1 705.50	37.90	1 705.50	37.90	1 705.50	37.90

Class of Employee	All Areas		All Areas		All Areas		All Areas	
	P W	P H	P W	P H	P W	P H	P W	PH
Grade 7	2 124.00	47.20	-	-	2 124.00	47.20	2 124.00	47.20
Grade 8	2 428.20	53.96	2 472.75	54.95	2 428.20	53.96	2 428.20	53.96
Watchman	981.04	no hourly rate	981.04	no hourly rate	981.04	no hourly rate	981.04	no hourly rate

APPRENTICES/LEARNERS ALL CHAPTERS All Areas	PW	PH
3 Year Trade		
First Year	1220.85	27.13
Second Year	1513.80	33.64
Third year	1860.75	41.35
4 Year Trade		
First Year	1220.85	27.13
Second Year	1339.20	29.76
Third Year	1513.80	33.64
Fourth Year	1860.75	41.35
NQF Learnership		
Level 1	1220.85	27.13
Level 2	1339.20	29.76
Level 3	1513.80	33.64
Level 4	1860.75	41.35
CBMT		
Level 1	1164.15	25.87
Level 2	1453.50	32.30
Level 3	1747.35	38.83
Level 4	2034.00	45.20

CHAPTER 3 MEASURING INSTRUMENT BONUS	PW
vernier/micrometer	13.80
tape/rule/square/sets	9.20

Provisions for Chapter 4 Operatives			GUARANTEED INCREASE	
MINIMUM	PW	PH	PW	PH
1. Op. Engine Assembler				
1st 18 Months Experience	1 419.30	31.54	105.30	2.34
Thereafter	2 124.00	47.20	157.50	3.50
2. Operative Grade A				
1st 12 Months Experience	1 419.30	31.54	105.30	2.34
Thereafter	1 705.50	37.90	126.45	2.81
3. Operative Grade B				
1st 6 Months Experience	1 165.50	25.90	86.40	1.92
Thereafter	1 273.05	28.29	94.50	2.10

* 8% Increase on actual earnings with effect from 1 September 2015 for Chapter 3 Establishments

DIVISION B & D - CLAUSE 3 (WAGES) - ALL CHAPTERS & SECTORS

WAGE SCHEDULE : MINIMUM WAGES - EFFECTIVE DATE 1 SEPTEMBER 2015

Class of employee	SECTORS 1,2,3,4,5 & 7				SECTOR 6 ONLY				SECTORS 1(ch 2),2,3,4,5,& 7	
	Minimum Wages				Minimum Wages				GUARANTEED INCREASES	
	Area A		Other Areas		Area A		Other Areas			
	P W	P M	P W	P M	P W	P M	PW	P M	PW	PM
(a) Office, stores sales and	R	R	R	R	R	R	R	R	R	R
Clerical employee-										
during 1st year of experience	1016.54	4405.01	1016.54	4405.01	1037.49	4495.79	1037.49	4495.79	75.30	326.30
during 2nd year of experience	1159.89	5026.19	1159.89	5026.19	1181.94	5121.74	1181.94	5121.74	85.92	372.32
during 3rd year of experience	1335.83	5788.60	1335.83	5788.60	1362.25	5903.08	1360.44	5895.24	98.95	428.78
thereafter	1550.88	6720.48	1550.88	6720.48	1579.06	6842.59	1557.33	6748.43	114.88	497.81
(b) Motor vehicle sales person-										
During 1st year of experience	1226.51	5314.88	1226.51	5314.88	1226.51	5314.88	1226.51	5314.88	90.85	393.68
thereafter.	1581.35	6852.52	1574.50	6822.83	1581.57	6853.47	1574.56	6823.09	117.14	507.61
(c) Bookkeeper	1993.95	8640.45	1992.20	8632.87	2011.22	8715.29	2002.24	8676.37	147.70	640.03
(d) Accountant	3392.04	14698.84	3363.04	14573.17	3436.89	14893.19	3388.19	14682.16	251.26	1088.79
(e) Parts salesperson -										
During 1st year of experience	1278.42	5539.82	1278.42	5539.82	1283.69	5562.66	1283.69	5562.66	94.70	410.37
thereafter	1570.42	6805.15	1569.20	6799.87	1570.42	6805.15	1563.14	6773.61	116.33	504.10

Class of Employee	All Areas		All Areas		All Areas	
	P W	P M	P W	P M	P W	P M
(f) Traveller -						
during 1st year of experience	1283.69	5562.66	1283.69	5562.66	95.09	412.06
thereafter	1570.42	6805.15	1570.42	6805.15	116.33	504.10
(g) Supply sales person -						
during 1st year of experience	1283.69	5562.66	1283.69	5562.66	95.09	412.06
during 2nd year of experience	1470.41	6371.78	1470.73	6373.16	108.92	471.99
during 3rd year of experience	1648.26	7142.46	1648.26	7142.46	122.09	529.06
thereafter	1768.89	7665.19	1768.89	7665.19	131.03	567.80
(h) Part-time employees	*	*	*	*		

* One eleventh of the minimum weekly wage as prescribed for clerical employees in (a) hereof, for ordinary time worked on each day on any one week, or one forty-fifth of such prescribed minimum weekly wage for each hour or part of an hour of ordinary time worked in any one week, whichever is the greater.