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Balancing the planned and actual production time within a steelwork fabrication company

Marisca van Zyl
u12203654

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UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

DEPARTEMENT BEDRYFS- EN SISTEEMINGENIEURSWESE
DEPARTMENT OF INDUSTRIAL AND SYSTEMS ENGINEERING

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Persoonlike besonderhede / Personal details	
Studentenommer **Student number**	12203654
Voorletters en van **Initials and surname**	M v Zyl
Titel **Title**	Mej
Selnommer **Cell number**	078 355 8183
Werkopdrag / Assignment	
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Abstract

In order to be sustainable in an ever growing competitive market, optimisation is required in a company to remain reliable and respond to change. The steel fabricator, Louwill Engineering, is faced with an imbalance in planned and actual production times in their workshop which leads to late delivery of items to succeeding companies in the inter-company supply chain and furthermore to overall late delivery of orders to site.

Inefficient material flow in the fabrication facility, high levels of work-in-process inventory and non-aligned prioritization of jobs are identified as the major causes of this problem. This project focusses on eliminating wasteful time in the fabrication process and improving the material flow within the fabrication process with the aim of achieving a balanced state in the production time of items.

Literature research was done to identify the most appropriate techniques and methodologies to use in solving the above-mentioned causes of the imbalance production time problem. The research reviews different simulation techniques, facility layout alternatives and development algorithms and facility alternative selection methods.

A simulation optimisation methodology is developed as a solution to address the imbalance production time problem. The methodology consists of the integration of simulation modelling and facility layout design. The fabrication process of Louwill is modelled as a Discrete Event Simulation and different facility layout alternatives are developed by means of the systematic layout planning procedure and alternative improvement opportunities. The Preference Selection Index method is used to identify the best facility alternative among those tested for the fabrication workshop.

The selected best facility alternative along with two other alternatives are analysed by means of a comparative study. This study analyses the affect of a pure layout, a pure process and a combinational layout and process improvement have on the selection attributes. These selection attributes are the time an item spends in production, re-processes and storage areas and the time of moving an item between functional departments.

Based on the results of the Preference Selection Index (PSI) methodology and the comparative study it is recommended that the company changes the current facility layout to the recommended product layout. The recommended product layout consists of a U-shaped production line with the functional departments placed in the order of the fixed process sequence, recommended for the workshop. It is also recommended that the company implement the supplementary improvements opportunities and adopts the fixed process sequence suggested. These improvements will result in a reduction of the actual time an item spends in the fabrication workshop as it improves the material flow in the workshop, resulting in more balanced planned and actual production times of items.

The company itself, the succeeding intermediate companies in the inter-company supply chain, and the end customer will benefit from balancing the planned and actual production times of items. This balance will result in enhanced supply chain relationships, improved fabrication process performance, customer satisfaction, delivering of items in the promised lead time to the next intermediate company and overall on-time delivery to the end customer.

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Chapter 1

Introduction

In this chapter an overview of the project company, Louwill Engineering, is given as well as some background on the problem they are faced with in the manufacturing workshop and the main causes of this problem are discussed. The problem is formally defined in Section 1.3. Section 1.4 discusses the proposed solution to the imbalanced planned and actual production time of items and the methodology that was followed to generate the solution to the problem is discussed in Section 1.5.

1.1 Company background

Louwill Engineering is a project planning and steelwork fabricator that forms part of an inter-company supply chain that focusses on medium and large engineering steel-and-plate work projects for the mining and smelting industries. The projects the inter-company supply chain focusses on consist of complete fabrication, sandblasting, powder-coating and painting of the items fabricated, the comprehensive construction, commissioning and the delivering of completed items. The different companies as well as their individual roles in the inter-company supply chain are represented in Figure 1.1.

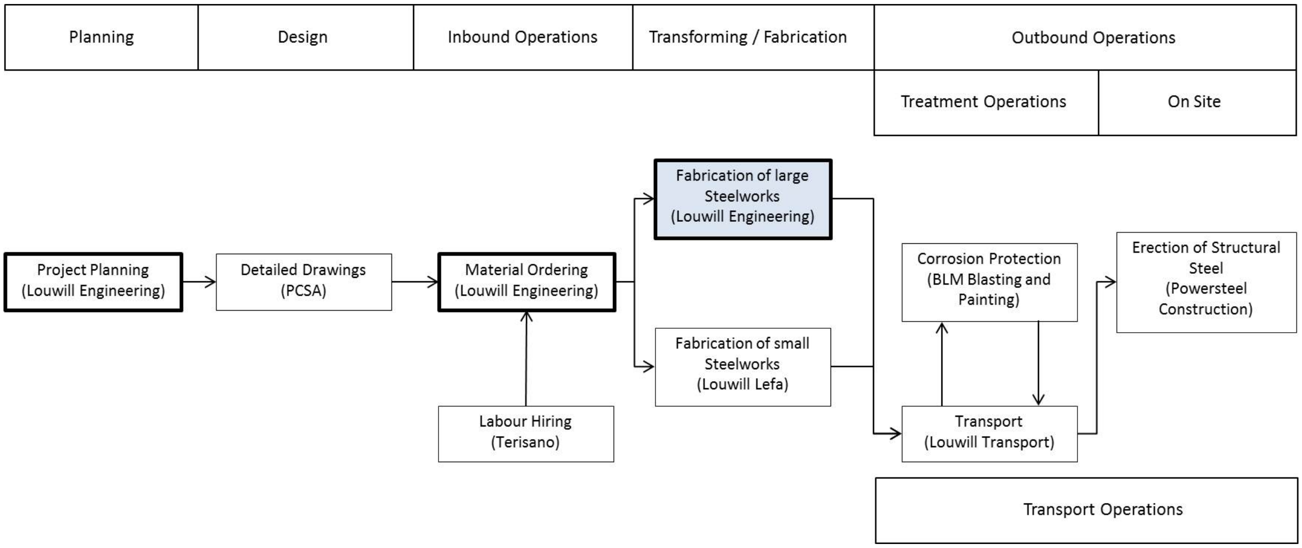

Figure 1.1: Internal Supply Chain

This project focusses on Louwill Engineering as a fabricator. Louwill manufactures a variety of different steel, mesh, pipe and plate work items that vary in size, shape, product spread and to same extent in the sequence of manufacturing processes, contributing to the complexity of the inter-dependent fabrication system. The fabrication takes place in a single workshop on site. The current fabrication activities in the workshop include:

- steel, mesh, pipe and plate cutting and bending;
- pre-cleaning of the raw material components;

- assembling;
- work-in-process quality inspection after assembling;
- hole-making:
  - hole punching (steel thickness$\leq 16mm$); and
  - hole drilling (steel thickness $> 16mm$).
- welding;
- work-in-process quality inspection after welding;
- cleaning and fettling; and
- final quality inspection.

Most items are produced through plate cutting, assembling, hole making, welding, cleaning and fettling. Currently the sequence of processes, such as welding and hole-making, differs between items as minimum idling of workstations are a priority in the workshop.

The company uses job shop processing; all work is done on orders received and items based on detailed design drawings are fabricated in small quantities. As defined by Stevenson (2012), a process layout consists of groupings of functional departments that performs similar kinds of activities. The facility layout of Louwill's workshop can be characterised as a process layout with dedicated buffer areas for functional departments. Overhead cranes and small trolleys are used to move material between workstations in the workshop's rows, also known as the bays, and fixed-path trolleys are used to move material between the two bays in the workshop. Figure 1.2 shows the current layout of the workshop, the current positions of the fixed path material handling equipment and the material receiving and dispatch areas.

Figure 1.2: Current Workshop Layout

1.2 Problem background

The fabrication workshop plays a fundamental role in the inter-company supply chain as the production time of items affect the job scheduling of succeeding companies. Scheduling of activities such as painting, sandblasting and powder-coating in succeeding companies are done based on promised lead times from the fabricator.

Any imbalance in the planned and actual production time of Louwill has a snowball effect on the remaining intermediate companies in the inter-company supply chain. This imbalance mainly leads to items and orders being delivered after the promised delivery date to the next intermediate company which generally results in late delivery to site.

Any deviation from the promised lead time of orders directly affects Louwill's performance and costs. The fabrication workshop's capacity $[tonnes/month]$ is based on the planned production time of orders each month, thus deviation from the planned production time leads to high levels of overtime in the workshop in order to fabricate the required tonnages in a month.

Figure 1.3 visually depicts the uncontrolled behaviour of the system. The differences in $[days]$ between the planned (P_{ij}) and actual (A_{ij}) production time of items of a data sample are plotted. The area above the zero point indicates the imbalanced production time items $(A_{ij} > P_{ij})$, which amount to 60% of the sample population. In the sample population the actual production time of items are in some cases as much as 30 days longer than the planned production time, excluding the extended production periods due to assignable causes. This emphasises the importance of addressing the imbalanced production time problem. Having 40% (excluding the rush job items) of the sample population items below the zero point verifies that the process is capable of fabricating items within the planned production time, thus confirming that the promised lead times are realistic.

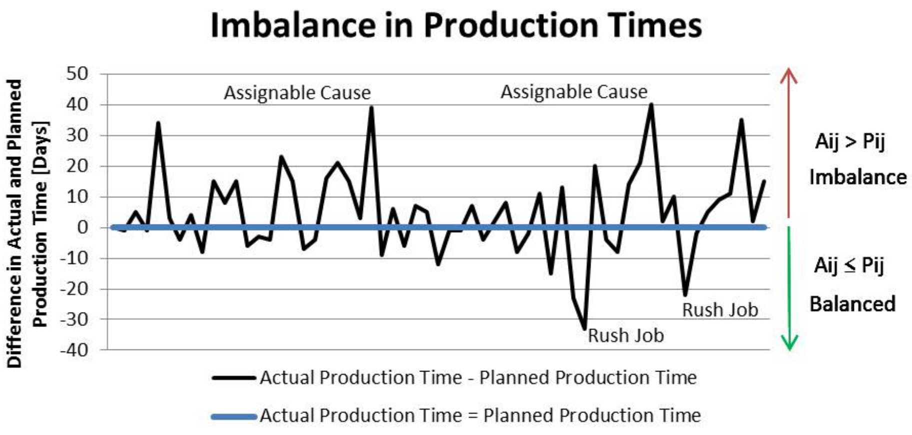

Figure 1.3: Uncontrolled Behaviour of the System

1.3 Problem statement

The main problem the company is faced with is the imbalance in the planned and actual production time of items.

The planned production time (P_{ij}) of an item refers to the time $[days]$ that the item is supposed to be fabricated in. The planned production time is calculated from the fabrication time estimation guidelines and the drawing indicated weight of the item. The estimated fabrication time is based on the detail of the design and the specified type of steel to be used. The promised lead time of an item is determined as the sum of the planned production time and the mean of the material receiving lead time distribution. The material receiving lead time is normal-distributed with a mean of 9 *days* and standard deviation of 4 *days*, determined through data analysis.

The actual production time (A_{ij}) of an item is the genuine time the item spends in the fabrication workshop measured in [*days*]. The production time of an item is calculated from the time the material is received and issued to fabrication until a final quality check is completed.

The imbalanced production time problem can formally be defined as:

$$A_{ij} > P_{ij} \tag{1.1}$$

where:

$$A_{ij} = F_{ij} - M_{ij} \quad [days] \tag{1.2}$$

$$P_{ij} = \frac{E_{ij}}{B} \times T_{ij} \quad [days] \tag{1.3}$$

and:

- → A_{ij} = the actual production time of an item of detail type i and steel type j [*days*];
- → P_{ij} = the planned production time of an item of detail type i and steel type j [*days*];
- → F_{ij}= the actual fabrication completion date of the item of detail type i and steel type j;
- → M_{ij} = the issuing date of material to fabrication for the item of detail type i and steel type j;
- → E_{ij}= the estimated fabrication hours per tonne of an item of detail type i and steel type j [*hours/tonne*], the guidelines used for the estimation is given in Table 1.1;
- → B = the average actual production hours per working day [*hours/day*], the working hours per shift is obtained from the shift schedules of the workshop presented in Appendix I;

$$B = \sum_{day=Monday}^{Friday} \frac{\text{Working hours per Shift}_{day}}{5 \text{ working days per week}} \tag{1.4}$$

- → T_{ij} = the weight of the item of detail type i and steel type j [*tonnes*];
- → i = the design detail of an item based on the type of item, where

$$i \in \begin{cases} 1 = & \text{little design detail;} \\ 2 = & \text{fair design detail; and} \\ 3 = & \text{specific design detail.} \end{cases}$$

- → j = the type of steel to be used specified in the detailed drawing categorised based on kg/m, where

$$j \in \begin{cases} 1 = & \text{light steel;} \\ 2 = & \text{medium steel; and} \\ 3 = & \text{heavy steel.} \end{cases}$$

	Estimation Parameters		
Categories	**Steel Type**	**Detail Type**	**Estimated Production Time**
$[kg/m]$	j	i	E_{ij} $[hours/ton]$
kg/m ≤ 25	Light steel	Little design detail	3
		Fair design detail	5
		Specific design detail	8
$25 >$ kg/m ≤ 49	Medium steel	Little design detail	8
		Fair design detail	8
		Specific design detail	8
kg/m ≥ 50	Heavy steel	Little design detail	8
		Fair design detail	8
		Specific design detail	8

Table 1.1: Fabrication Time Estimation Guidelines used by Project Management

The major causes of the imbalance in the planned and actual production time of items are defined through analysis of:

- gathered data on planned production and actual work issuing and completion reports;
- work, information and material flow studies within the workshop;
- activities performed on the workshop floor; and
- process mapping and workshop layout analysis.

The major identified causes of this imbalance in fabrication times are as follows:

- zig-zag material flow;
- high levels of work-in-process inventory; and
- non-aligned prioritizing of work between project management and the workshop and between different functional departments.

Zig-zag material flow occurs as functional departments performing consecutive activities are currently positioned far apart and in different bays on the workshop floor. The main cause of the inefficient material flow is the current facility layout that does not take the fixed positions and direction of flow of the material handing equipment into consideration. The actual production time (A_{ij}) of an item is increased with the wasteful time of moving the item around in the workshop.

High levels of work-in-process inventory exist due to an imbalance in the work and time load placed on different functional departments. This imbalance leads to the formation of bottlenecks and idle workstations in the system. The actual production time (A_{ij}) of an item increases with the non-value-adding time it spends in buffer areas contributing to the main imbalanced production time problem. The formation of bottlenecks limits the throughput capacity of the fabrication process.

The non-aligned prioritizing of work between project management and the workshop contributes to the imbalance of planned and actual production times as jobs in the workshop are scheduled in a non-optimized sequence. This leads to late delivery of items to the succeeding companies in the inter-company supply chain and furthermore to overall late delivery of an order to site. The incorrect job scheduling also leads to rush jobs being pushed into fabrication which in turn causes the work-in-process levels in the system to increase as non-rush job items are moved aside to first complete the rush job item. According to management, fabrication prioritization differs between functional departments as each department is focussed on achieving maximum throughput measured in $[tonnes/month]$ in the specific department. This item and work prioritization of functional departments contributes to the high levels of work-in-process at buffer areas.

Addressing these identified causes of the main problem will reduce the actual production time (A_{ij}) of items which in turn will contribute to the desired state of balanced planned and actual production time in the workshop. The planned and actual production times are regarded to be balanced if:

$$Actual(A_{ij}) \leq Planned(P_{ij}) \tag{1.5}$$

The principle objective is to transform the current process to an in-control process were the actual production time of items are smaller or equal to their planned production time. This will contribute to Louwill meeting promised lead times and planned workshop capacity, without incurring extra costs or sacrificing customer satisfaction. Solving the imbalanced production time problem will ensure that items are delivered on time to succeeding companies in the inter-company supply chain and to sites.

1.4 Research design

The project is focussed on balancing the planned and actual production times of items through addressing an identified cause of the main problem, namely zig-zag material flow. Solving this problems will contribute to the company's on-time delivery of items and orders.

The research design of this project is based on approaches followed in similar industrial problems, identified through literature research.

A dynamic Discrete Event Simulation model is built to model the fabrication process of the company. Alternative facility layouts and improvement opportunities are developed to improve the material flow within the fabrication facility with the aim of reducing the actual time an item spends in the workshop. The alternative facility layouts that are generated using the systematic layout planning procedure are based on material flow frequencies and other relevant factors. The Preference Selection Index is used to identify the best facility alternative among the alternatives tested for the workshop, that leads to balanced production times of items.

The average production time [$hours/tonne$] of an item is the measure of interest and is obtained as a simulation output. This measure is analysed and compared to the estimated production time of the type of item (E_{ij}) to analyse the improvement of the system. The other measures of interest the average total processing time, re-processing time and non-value-adding time of items and the average total time items spent in the workshop.

1.5 Research methodology

Data gathering was done through work sampling, observations, analysis of the planned and actual production times (dating from 2014) and data provided by management on facility dimensions, current staffing, equipment and the number of workstations in each functional department. A data analysis was done and the process and material flow within the fabrication facility were mapped out.

Literature research was done to identify the following:

- the appropriate simulation modelling technique to use;
- the technique to use in developing facility layout alternatives; and

- the algorithm to use in selecting the best layout alternative for the fabrication facility.

The current fabrication process was modelled as the "base case" in Anylogic and validated with the actual data. Facility alternatives for the current process and the recommended fixed sequence process were developed and modelled to obtain selection attributes for each alternative as an output from the simulation model. The best alternative among those tested was selected and the improvements analysed and compared to the base case and other possible alternatives.

The flow diagram in Figure 1.4 summarizes the complete research methodology followed in this project.

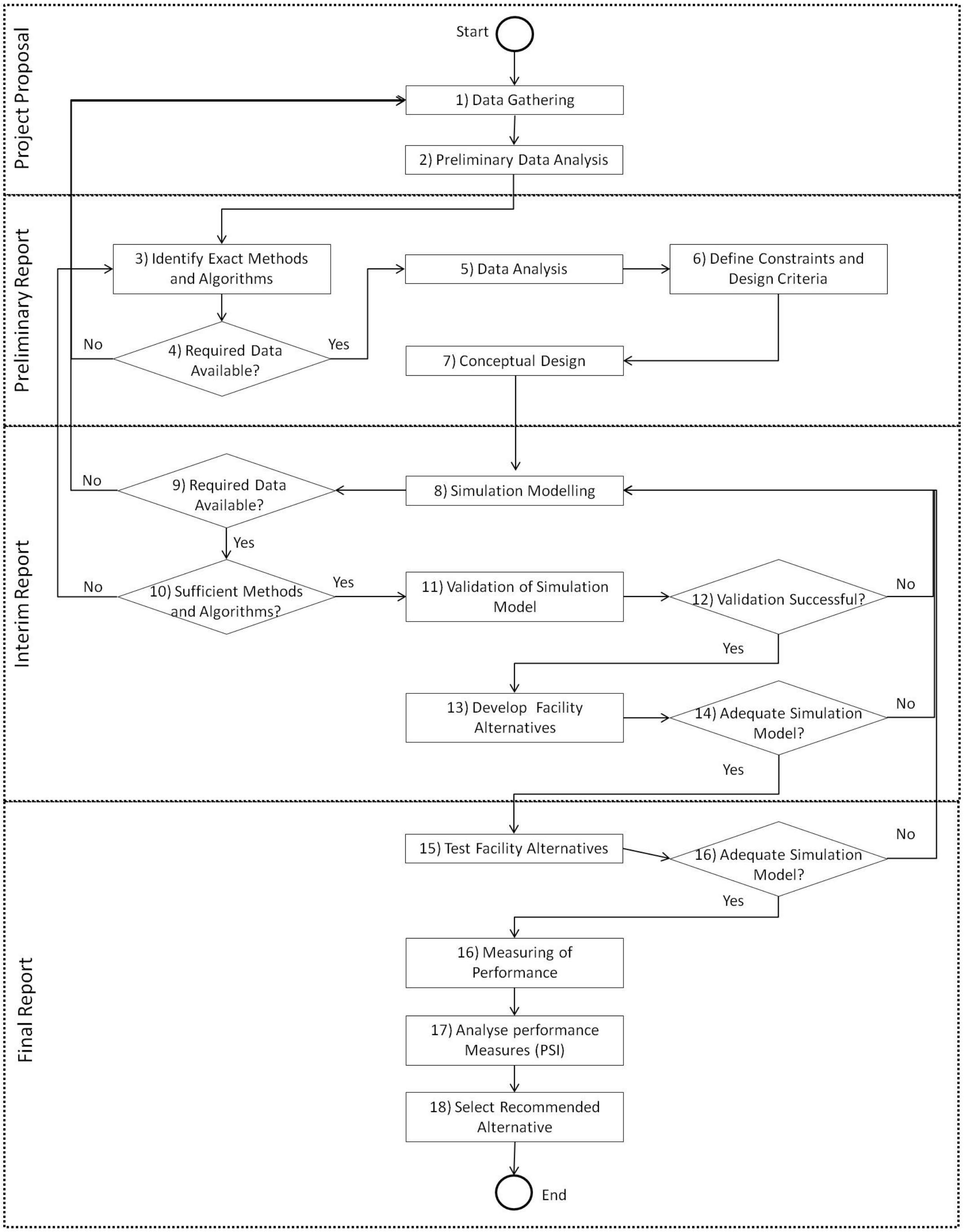

Figure 1.4: Research Methodology Process Followed

1.6 Document structure

The remaining part of this document consists of a literature review, solution development, results analysis, recommendations and a conclusion.

Literature research on simulation modelling, facility layout alternatives and planning algorithms, and alternative selection algorithms is discussed in Chapter 2. The applicable research and report scenarios are reviewed followed by a discussion of how the research is applicable to this project, the instances of the researched problem types used further in the project and the techniques applied.

In Chapter 3 the logical design of the simulation model and the development of the fabrication facility alternatives are discussed as well as the data used in these developments and how it was used. Section 3.3 in this chapter describes the selection attributes used to compare the alternative layouts with one another and formulates the variables used in the selection algorithm.

In Chapter 4 the selection of the best facility alternative, among those tested, is discussed. The results and the improvement opportunity of the selected alternative and other feasible options are compared and discussed.

Recommendations are made to the project company based on the results of the Preference Selection Index (PSI) methodology and the comparison study of improvement facility alternatives in Chapter 5.

Chapter 6 concludes the project by discussing how the imbalanced production time problem was addresses and by giving the results of the project. Opportunities for further research are discussed in this chapter.

Chapter 2

Literature review

In this chapter the related work done in literature are researched and analysed and its relevance to the project discussed.

2.1 Simulation modelling

Simulation modelling is a decision support tool. Simulation can successfully be used in analysing numerous complex stochastic industrial manufacturing systems. It allows taking decision variables into account and mapping it to a set of performance measures that describes the behaviour of the manufacturing system.

Mahfouz et al. (2011) summarizes the advantages of using simulation modelling and concludes that simulation modelling assists with:

- discovering intricate factors and parameters in the manufacturing process;
- identifying and exploring different process improvement opportunities;
- anticipating affects of changes before implementation;
- value stream mapping of the future state of the organization; and
- analysing the interaction between system components and parameters and the impact they have on the rest of the organization.

The unique characteristics of simulation techniques make it applicable to certain types of problems. According to Anylogic's definition Software (2016) of simulation techniques, Discrete Event Simulation (DES) is the modelling of continuous real-world processes as non-continuous discrete events to simplify the analysis of processes and systems. Discrete Event Simulation renders itself mostly to models where changes are driven by irregular time interval events. System Dynamic (SD) models are identified as being most appropriate for modelling continuous systems were individual properties of discrete items can be abstracted and individuals modelled as continuous quantities. Where as Agent-Based Simulation (ABS) is mostly used to model systems that are largely dependent on individual objects' behaviours, their unique properties, the intention and desire of interactions between objects, and their complex relationships.

Su and Gitae (2016) summarize the applicable simulation techniques for different production and planning control problems in manufacturing environments after analysing the properties of the state-of-the-art simulation techniques and reviewing the properties of production planning issues. Table 2.1 (extracted from their article) is a summary of the applicable simulation techniques for different manufacturing problems. Their article concludes that DES modelling is most appropriate for production system and layout modelling which include resource, capacity, process and job planning, and production process and multi-agent modelling. Table 2.2 depicts the application ratio of simulation techniques in literature extracted from their review.

PPC Problems		Applicable Simulation Techniques			
			DES	SD	ABS
Production Planning	Facility Resource Planning	Location Determination	✓		
		Layout Design	✓		
		Resource Management	✓	✓	✓
	Capacity Planning	Optimal Quality for Planning Horizon	✓		
		Forecasting with Demand Uncertainties		✓	
		Optimal Capacity Selection	✓	✓	
	Job Planning	Equipment Planning	✓		✓
		Job Shop Planning and Management	✓		✓
		Machine Job Sequence Planning	✓		✓
	Process Planning	Bottleneck Problems	✓		
		Process Sequence Planning	✓		
		Machine Routing	✓		✓
		Material Process Planning	✓		✓
Production Control	Shop Floor Scheduling	Shop Floor Scheduling	✓		✓
		Schedule Management	✓	✓	✓
	Inventory Management	Product Shortages/Product Overstock	✓	✓	✓
		Forecast Inventory Turnover Ratio	✓	✓	✓
	Production and Process Design	GT, Functional Layout Design			✓
		Production Layout Modelling			✓
	Purchase and Supply Management	Appropriate Order Time/Order Quantity	✓	✓	✓
		Network Transportation Planning, SCM		✓	✓

Table 2.1: Applicable Simulation Techniques Summary

Simulation Technique	Application ratio
Discrete Event Simulation (DES)	45 %
Agent-Based Simulation (ABS)	28 %
System Dynamic Modelling (SD)	10 %
Hybrid Approach (HB)	17 %

Table 2.2: The Application Ratio of Simulation Techniques

According to Negahban and Smith (2014) it is proven that simulation is applicable over a wide range of applications. In their review article the use of simulation modelling for optimizing a facility layout, planning of production and scheduling of jobs, are some of the implementation fields discussed.

The main problems causing an imbalance in the planned and actual production time of items within Louwill Engineering leans itself to facility resource, capacity and process planning which according to Su and Gitae (2016) are part of production planning. Based on the results obtained from their study, and the application fields of simulation obtained from the study of Negahban and Smith (2014), DES is used to model the fabrication process of the project company.

Wang et al. (2008) state that simulation is only a test approach of which the optimisation objectives are unclear and therefore proposes that optimisation techniques be integrated with simulation modelling to provide an effective means for optimisation problems.

Vasudevan et al. (2010) describe the application of simulation with other industrial engineering techniques to improve the efficiency of the company. They integrate simulation with facility layout, cycle times, material-handling, and production scheduling to design an optimized steel mill manufacturing plant.

This project integrates simulation modelling with facility layout planning, and an optimal facility layout design alternative selection methodology with the objective to balance the planned and actual production times of items.

2.2 Facility layout alternatives

A facility's layout is the way the facility is arranged to contribute to effective and efficient work flow. A facility's layout is the physical arrangement of a production system. The solution to a facility layout problem (FLP), which is a non-deterministic polynomial-time hard (NP-hard) problem, is the relative location of departments in a block layout.

According to Maniya and Bhatt (2011) a facility's layout affects the efficiency of workers and workstations and the responsiveness of the system to change. An optimized layout contributes to improved material handling and flow, increased fabrication throughput and productivity and the reduction of work-in-process inventory levels, idle times and the total fabrication time of items.

Based on the above-mentioned implications that the layout of a facility has on productivity, facility layout planning is incorporated in the project to improve the material flow in the fabrication workshop of Louwill. The aim of the facility layout planning is to reduce wasteful time of moving items between workstations leading to the balanced planned and actual production time of items.

Stevenson (2012) states that there are four main types of facility layouts, namely process-, product-, fixed position- and the combinational type facility layout. In a process or functional layout workstations are arranged and located in groups according to the nature or type of the operations they perform. In the product or line layout workstations are arranged according to the sequence of operations of the process. In a fixed position layout the position of the product is stationary and machines and equipment are brought to the fixed position of the product to perform required operations. If a combination of the above-mentioned layouts is used, the layout is known to be a combinational type of layout.

Supported by the article of Hungerlandera and Anjosb (2015), there are three main types of facility layout problems, namely single-row, double-row and multi-row layout problems. In their article they define and discuss the different layout problem types. The single-row facility layout problem (SRFLP) is defined as departments that need to be placed next to each other along a single row. The solution of a SRFLP is to find the optimal arrangement of the departments along the row. In a double-row facility layout problem (DRFLP) it is required that departments be assigned to one of two rows and then be located at a specific position within the specified row. The multi-row facility layout problem (MRFLP) is an extension of the DRFLP which requires departments to be assigned to one of the multiple rows in the facility and then allocated to a specific position within the specified row.

Determining the physical arrangement of functional departments at Louwill is a double-row facility layout problem (DRFLP), as the workshop has two bays each equipped with its own fixed path material moving equipment as represented in Figure 2.1. The fabrication facility layout problem of the company is identified as a DRFLP rather than a MRFLP as workstations of a functional department can be located across an aisle of a bay.

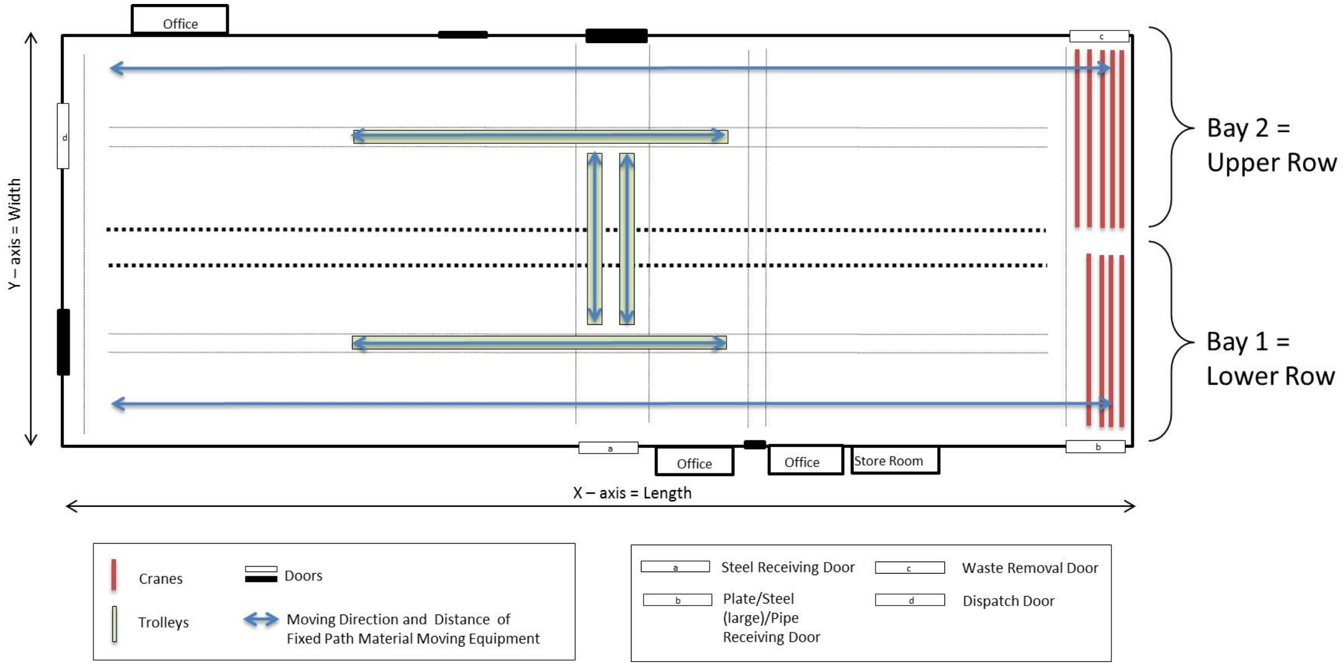

Figure 2.1: Double-Row Facility Layout of the Fabrication Facility

Singh and Sharma (2006) review trends in facility layout problems focussing specifically on manufacturing plants. They give a description of the formulation of FLP and discuss various solution methodologies for solving these problems. Facility layout problems can be formulated as a quadratic assignment problem (QAP), through a graph theoretic approach or with a mixed integer programming (MIP) model. The QAP model works with binary variables and is aimed at assigning departments to different locations with the goal of minimizing the makespan and the flows or travelling distance of items. A FLP that is formulated as a QAP model can be solved through branch and bound methods or heuristics. Heuristic algorithms are a construction type algorithm that constructs an initial solution and optimizes it through improvement algorithms. The branch and bound methods and heuristic algorithms are appropriate for solving small scale facility layout problems. The graph theoretic model is dependent on predefined adjacencies of department pairs, it models departments as nodes within a graph network. MIP models minimise the rectilinear distance between departments' centroids. Meta-heuristics are used to solve large facility layout problems. Meta-heuristics consist of tree categories namely simulated annealing (SA) algorithms that generate a single solution, genetic algorithms (GA) that generate a population of candidate solutions, and swarm intelligence algorithms such as the ant colony optimisation and artificial bee colony algorithms that generate a solution based on mutual behaviour of components. Singh and Sharma (2006) also identify some of the other solution methodologies used in literature such as the tabu-search algorithm, neural network, fuzzy logic and expert system (Deb and Bhattacharyya, 2005).

Chung and Tanchoco (2010) suggest the P-formulation MIP model. This model neglects the width of a corridor between rows within a double-row facility layout. The suggested model firstly allocates departments to a specific row and thereafter allocates the departments to a specific location within the allocated row.

Inc (2016) suggests a MIP model that assigns rectangular objects to a large space to solve the layout planning problem. In the model the workshop is modelled as a matrix consisting of zeros and ones that indicate whether a squared-meter area is available or occupied. The model minimizes the distance between the rectangular workstations to minimize the material flow in the workshop. After assigning the workstations to specific positions the layout is visually depicted in the form of the workshop matrix filled with zeros, ones and alphabet letters indicating the workstations.

Tompkins et al. (2010) refers to muther's systematic layout planning (SLP) method as a solution to layout problems. The SLP method is used to systematically create facility layout alternatives. The SLP method is a combination of the quadratic assignment and the graph theoretic approach. The construction procedure followed in the SLP method is as follows:

1. Material flow diagram.
2. Activity relationships/ from-to chart.
3. Relationship diagram.
4. Space requirements.
5. Space availability.
6. Space relationship diagram.
7. Facility layout alternatives.

Krishnan et al. (2011) substantiates the important use of a from-to chart as a primary input in facility layout planning. They use the from-to chart to identify flow dominance between departments and to order the closeness of departments in a facility layout design. A from-to chart is used to present the relationship between a set of points.

Research shows that the SLP and MIP algorithms combined with heuristic methods are mostly used in solving double-row facility layout problems. In this project the SLP method is used to generate optimized alternative facility layouts that take the material flow frequencies between department, depicted in a from-to chart, and the fixed position and direction of flow of material handling equipment into account. The heuristics methods for optimizing the layout alternatives are replaced with a facility layout design selection algorithm to select the optimal facility alternative among the different alternatives tested. This selection method is used rather than a heuristic algorithm to take dynamic factors affecting the operation of the layout into account.

2.3 Facility alternative selection algorithms

Literature review shows that multi-attribute decision making (MADM) methods are largely used in the selection of an optimal facility layout design. The MADM method requires the decision maker to assign a weight or to allocate a comparative importance to each facility layout design selection attribute.

The Preference Selection Index (PSI) method as an alternative decision making methodology to select the optimal facility alternative is proposed by Maniya and Bhatt (2011). This method is ideal for decision makers that are less experienced with determining the relative importance between different facility layout design attributes.

Maniya and Bhatt (2011) proposed methodology is used to select the optimal feasible facility layout alternative with the use of the simulation output measures. In this project the PSI methodology is used because it is user friendly, systematic and logical and there is no need to assign a weight or to allocate a comparative importance to the attributes; reducing the change of improper final selection of a facility layout for the fabrication workshop due to inexperience.

The PSI methodology summarizes the quantitative design selection attributes' performance of the tested layouts, which is obtained as output measure from the simulation model, into a decision matrix. The performance ratings, thus the measured attributes that have different measurement units, are then transformed into a compatible unit through normalization into a normalized decision matrix. The mean value, the preference variation value, the deviation in the preference values, an overall preference value, and a selection index value are calculated from the normalized data for every layout alternative. For the selection of the most optimal facility layout alternative the layouts are ranked according to their selection index values. The optimal facility layout alternative is then selected based on the lowest or highest selection index, based on the type of attributes used. If the specified layout is not feasible the following alternative layout is selected in ascending or descending order of the selection index value.

The variables used throughout the PSI methodology can be defined as follows;

→ Y_i = the set of facility design alternatives for $i \in$ 1, 2, 3, ... , n;

→ C_j = the set of facility layout design decision attributes for $j \in$ 1, 2, 3, ... , m; and

→ x_{ij} = the quantitative performance of alternative Y_i when it is evaluated with criteria C_j.

The steps followed in the methodology to select the best facility alternative (Y_i) are as follows:

- For all the facility layout design selection attributes and every facility design alternative, thus for $\forall i, j$:

  1. Formulate a decision matrix from the measured performance (x_{ij}) of the facility layout design attribute simulation outputs for each layout alternative.

$$\begin{array}{cc} & \begin{array}{cccccc} C_1 & C_2 & ... & C_j & ... & C_m \end{array} \\ \begin{array}{c} Y_1 \\ Y_2 \\ \vdots \\ Y_i \\ \vdots \\ Y_m \end{array} & \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1j} & \dots & x_{1m} \\ x_{21} & x_{22} & \dots & x_{2j} & \dots & x_{2m} \\ \vdots & \vdots & \vdots & \vdots & \dots & \vdots \\ x_{i1} & x_{i2} & \dots & x_{ij} & \dots & x_{im} \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \dots & x_{nj} & \dots & x_{nm} \end{bmatrix} \end{array}$$

  2. Transform the performance ratings, thus the measured attributes that have different measurement units, into a compatible unit through normalization:

     – beneficial attributes (the larger the better)

$$N_{ij} = \frac{x_{ij}}{x_{j,max}} \quad \text{where} \quad x_{j,max} = max(x_{ij}) \tag{2.1}$$

     – non-beneficial attributes (the smaller the better)

$$N_{ij} = \frac{x_{j,min}}{x_{ij}} \quad \text{where} \quad x_{j,min} = min(x_{ij}) \tag{2.2}$$

  3. Formulate a normalized decision matrix.

$$\begin{array}{cc} & \begin{array}{cccccc} C_1 & C_2 & ... & C_j & ... & C_m \end{array} \\ \begin{array}{c} Y_1 \\ Y_2 \\ \vdots \\ Y_i \\ \vdots \\ Y_m \end{array} & \begin{bmatrix} N_{11} & N_{12} & \dots & N_{1j} & \dots & N_{1m} \\ N_{21} & N_{22} & \dots & N_{2j} & \dots & N_{2m} \\ \vdots & \vdots & \vdots & \vdots & \dots & \vdots \\ N_{i1} & N_{i2} & \dots & N_{ij} & \dots & N_{im} \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ N_{n1} & N_{n2} & \dots & N_{nj} & \dots & N_{nm} \end{bmatrix} \end{array}$$

- For every facility layout design selection attribute, thus for $\forall j$:
    4. Calculate the mean value of the normalized data.

$$\bar{N_j} = \frac{1}{n}\sum_{i=1}^{n} N_{ij} \tag{2.3}$$

    5. Calculate the preference variation value (Π_j).

$$\Pi_j = \sum_{i=1}^{n}(N_{ij} - \bar{N_j})^2 \tag{2.4}$$

    6. Determine the deviation (Φ_j) in the preference values.

$$\Phi_j = |1 - \Pi_j| \tag{2.5}$$

    7. Determine the overall preference value (Ψ_j).

$$\Psi_j = \frac{\Phi_j}{\sum_{j=1}^{m}\Phi_j} \quad \text{and} \quad \sum_{j=1}^{m}\Psi_j = 1 \tag{2.6}$$

- For every facility layout alternative, thus for $\forall i$:
    8. Compute the facility layout design selection index (Ω_i) for every layout alternative.

$$\Omega_i = \sum_{j=1}^{m}(N_{ij} \times \Psi_j), \quad \forall i \tag{2.7}$$

- For the selection of the optimal facility design alternative:
    - For beneficial (the larger the better) attributes:
        9. Rank the the facility design alternatives (Y_i) in descending order according to the value of the design selection index (Ω_i).
        10. Select the facility alternative with the highest design selection index (Ω_i).
    - For non-beneficial (the smaller the better) attributes:
        9. Rank the the facility design alternatives (Y_i) in ascending order according to the value of the design selection index (Ω_i).
        10. Select the facility alternative with the smallest design selection index (Ω_i).

An attribute is a changeable property or characteristic of a component. Selection attributes used for facility layout optimisation should either be beneficial (the larger the better) or non-beneficial (the smaller the better) and can be quantitative or qualitative. Examples of quantitative attributes are materials handling cost or movement, work-in-process levels, throughput time. Examples of qualitative selection attributes are safety, flexibility, accessibility, maintenance and aesthetics. Quantitative non-beneficial selection attributes are used in this project as it is easily measurable in the simulation model and the focus of the project is to minimize the actual production time of items through minimizing the material flow in the workshop.

The literature review concludes that line balancing and job scheduling are large study fields on their own and that an optimized facility layout forms the bases for implementation of line balancing and scheduling methodologies. It is therefore recommended that the company's high levels of work-in-process inventory, which is primarily due to an imbalance in the work and time load placed on different functional departments, and the non-aligned prioritizing due to improper job scheduling, only be addressed after the material flow within the workshop is improved. Line balancing and job scheduling were therefore excluded from the scope of this project.

Based on the identified techniques to use for the simulation modelling, layout development and alternative selection, a conceptual design for the project is presented in the following chapter.

Chapter 3

Solution development

In Section 3.1 the data, assumptions and conceptual design used in the development of the simulation model are discussed. The model is verified and validated using the current state in the workshop as a base case. The data, assumptions, supplementary improvements, requirements and specifications used in the development of the facility alternatives are discusses and the alternatives showcased in Sub-section 3.2. In Section 3.3 the variables used in the facility layout selection algorithm are formulated and discussed.

3.1 Simulation model construction

A Discrete Event Simulation model was built in the Anylogic software to model the current state in the fabrication facility and to test the different developed facility alternatives. The simulation model was built to assist with:

- anticipating the affects of changes before implementation; and
- analysing the interaction between system components and parameters and the impact these have on the rest of the organization.

3.1.1 Input data analysis

The process and material flows within the fabrication facility were mapped out based on data gathered through work sampling, observations and analysis of the data gathered and received from management. The process and material flow diagrams are the bases on which the simulation model's logic was constructed on. Figure B.1 and Figure B.2, included in Appendix B show the current process flow within the fabrication facility as modelled with the Bigazi software. Figure C.1 and Figure C.2, included in Appendix C show the current material flow in the fabrication process and indicate the material handling equipment used in moving material between functional departments. The black arrows indicates the logical flow and the coloured arrows indicate the direction of material movement between departments and the means of the movement. The material moving equipment used are indicated as follows:

- the red arrow indicates that the material is moved by means of a fixed path overhead crane along the length of a bay;
- the green arrow indicates that the material is moved with a fixed path trolley, either along the length of a bay or from one bay to another;
- the blue arrow shows that material movement takes place by means of a human resource moving the material by hand; and
- the purple arrow indicates movement done by forklift.

The from-to chart represented in Figure K.1, included in Appendix K, indicates the flow frequency (f_{ij}) of material between the functional departments i and j. The process path an item follows in the simulation model is based on the flow frequencies depicted in the from-to chart.

Louwill manufactures a variety of items. The various items the company manufactures have been categorized into item groups (dependent on the item's characteristics) and into specific categories (depending on the item's steel and detail type). The items generated in the simulation modelling of the fabrication process are based on the demand distribution to generate a realistic item spread. Table D.1, included in Appendix D, summarizes the demand distribution of the item types and categories the project focusses on, obtained through data cleaning and analysis of the production records of the company for the periods of 2014 and 2015. The indicated percentages in the table shows the portion that each steel type, detail type and item type contributes to the demand production. The portion that each steel type contributes to the demand is listed as ST%. For each steel type the portion that each detail type contributes to that demand is listed as DT%, whereas the portion that each item type contributes to the specific detail type demand is listed as IT%.

The last column in the table lists the raw material each item is made of. The raw material an item is made of was used in the simulation model to model the correct pre-assembling processes an item goes through in order to obtain the correct average process time per item and the correct material flow in the workshop.

The average frequency of items issued to fabrication is depicted in Figure E.1 and Figure E.2, included in Appendix E. The frequency is obtained through data cleaning and analysis of the production records of the company for the periods of 2014 and 2015.

The production time of an item is dependent on the detailed drawing of the item and the specified standards, which directly impact the manufacturing processes. The data gathered from the informal job-card system implemented at the beginning of the year has been analysed to determine the time distributions of items for the different functional departments. The analysis identified that most of the items have a normal time distribution for most of the functional departments. Table F.1, included in Appendix F, summarizes the mean production times that were used as a simulation input for the time different items spent in specific departments.

The human resources have been assigned to specific departments, based on the specific type and number of workers required to execute tasks at the various workstations. Table H.1, included in Appendix H, shows the allocation of human resources to workstations required to handle one item, as well as the current available capacity of the different types of workers. This allocation was used in assigning resources to specific tasks in the simulation model.

3.1.2 Assumptions

Only the fabrication processes within the facility were simulated. The following activities and concepts were excluded from the scope of the simulation model as it is assumed that changes in the facility layout and production process has a negligibly small impact on these activities:

- waste removal;
- material delivering;
- item despatching;
- item picking at functional departments;
- machine breakdown and maintenance; and
- human resource behaviour (absences, energy-levels, etc.).

The buffer queue storage areas and workstations of processes were combined and modelled as single functional departments for the different fabrication processes. Only the movement from and to these functional departments was modelled as it is assumed that the time to move material from a process' storage area to its workstation and the time difference in moving items to and from different workstations in the functional department are negligibly small.

The production times of items were assumed to all be normally distributed for all of the functional departments, with a standard deviation of 2 hours for the assembling and welding processes and a standard deviation of half an hour for the drilling, punching and cleaning and fettling processes. The pre-assembling processes' times were assumed to all be triangular. This assumption is based on the data analysis of the job cards received, which revealed that most of the items have a normal time distribution for most of the functional departments. The process time of pre-assembling an item before it enters the pre-drilling or pre-punching process was assumed to be 0.3 times the actual assembly time of the item.

The process of moving an item between bays consists of unloading the item from the crane onto a vertical fixed path trolley, moving the trolley to the destination bay and offloading the trolley with a crane. The cranes were modelled to move at a speed of 10 m/s which is their current moving speed in the fabrication facility. The process time to move the item between bays is assumed to be triangular with:

- a minimum of 10 minutes;
- a mean of 15 minutes; and
- a maximum of 20 minutes.

3.1.3 Conceptual design

The logical process flow of the simulation model is based on the material and process flow diagrams and the from-to chart that depicts the material flow and the frequencies thereof between the functional departments.

The model is driven by a part entity that represents the items the project focusses on. The part entity consists of various characteristics, based on a random order generated from the demand distribution, and associated build-in parameters that set variables in the model as the entity passes through the fabrication process. Table G.1, G.2 and G.3, included in Appendix G, discuss the parameters embedded in the part-entity in the simulation model.

Items are generated by means of a source block with a triangular arrival rate based on the items issued to fabrication frequency. An item ID is assigned to the generated part-entity. The ID is used to follow the process-paths the item passes through and to calculate the average production hours per tonne for each specific steel and detail type, by means of keeping track of the number of items from the categories.

Each item is split into its raw material components at the start of the production process, which are duplicates of the main item. The raw material components then go through their individual pre-assembling processes, based on the exact type of raw material created and the flow frequencies between functional departments. After completion of the pre-assembling processes of the raw material components an assembling building block is used to combine the components again into the single initially generated item. The item then moves through the post-assembling processes, whereafter it enters a sink building block that represents the collecting process of items.

The process time of a functional department is modelled as delay building blocks. The delay time is based on the production time distribution of the specific item type and category for the specific department and is set as an item passes through the process. The number of workstations in a specific functional department is modelled in the capacity of the delay building block of that functional department.

The material movement is modelled in detail. The time to move an item between workstations depends on the specific material handling equipment or combination of material handling equipment used and the distance the item is moved.

Select blocks determine which department's queue an item is moved to, based on the material flow frequency between functional departments, after tasks allocated to the current workstation are completed.

Items are selected from the buffer queue in front of a department by the first operator available in that specific department. The relevant resources for each process are seized when needed and released after completion of the process, based on the human resource allocation and the material moving resources required. A shift schedule is used to model the time the workshop is in fabrication, based on the worker's shift schedules depicted in Table I.1, I.2 and I.3, included in Appendix I.

The model outputs are measure with various parameters and variables that measures data at various stages in the model. These output measures are exported to Excel, where further data analysis takes place.

3.1.4 Model Verification and Validation

The current facility layout was modelled in the simulation as the base case to verify and validate the simulation model. Verification and validation were done to ensure that the model is an accurate representation of the actual fabrication process and that the model addressed the requirements of its initialisation.

Verification was done by means of visual inspection and a walk-through of the execution of the model code. Colour parameters that are set by the items' raw material type were used to verify that the model creates exact copies of the initial items for the raw material components at the split building blocks. The same colour parameters were used at the re-combining of the items' raw material components to verify that the combined items are exact copies of the initial items. The model executed correctly and was therefore verified.

Validation of the model was done through executing the model and analysing the output results. The model was run multiple times, each for a ten year period. The average throughput of the model ranged between 330 and 390 *tonnes* per month, which relates closely to the actual throughput of the workshop of 350*tonnes* on average per month.

Figure 3.1, 3.2 and 3.3 compare the steel, detail and item type distribution generated by the model with the actual demand distributions. These serve as proof that the model represents the actual state in the company.

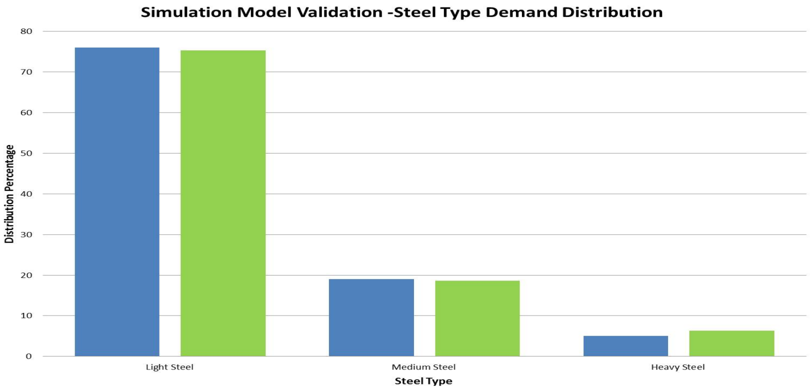

Figure 3.1: Steel Type Demand Distribution Validation

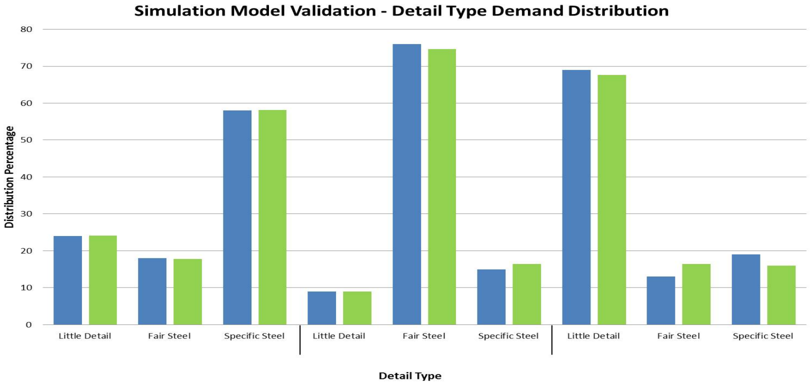

Figure 3.2: Detail Type Demand Distribution Validation

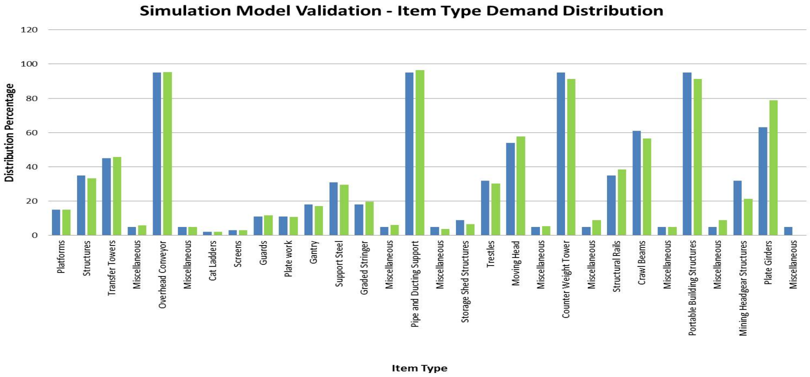

Figure 3.3: Item Type Demand Distribution Validation

The verification and validation confirm that the simulation model is valid to test alternative facility layouts and obtain realistic design attributes as outputs.

3.2 Facility alternatives development

Different facility layout alternatives were developed to minimize the material flow in the workshop to assist in the reducing of the actual production times of items.

3.2.1 Requirements and Specifications

The developed layout alternatives had to satisfy the stated requirements and specifications in order for it to be feasible and considered implementable by the management team of the company.

Requirements from management that guided the layout planning process and constrained the development of alternatives are as follows:

- the minimum clearance, in the horizontal direction, between any two workstations or a workstation and storage area, is $1m$;

- no workstation or part of a workstation or storage area may be placed over a driving zone, an aisle or a walkway;
- the workstations' floor area dimensions are the minimum area required by the workstation due to the size of machinery and the required working area allowance for the workstations;
- the dispatch storage areas' dimensions can only be increased as the current areas are the minimum required by the dispatch process;
- the receiving area and dispatch area must be located next to a door;
- the position of the plate cutting CNC machine is fixed;
- the cleaning & fettling department should be placed close to a door, due to the noise pollution caused by this workstation;
- the main aisles, walkways and driving zones cannot be changed in size or repositioned ;
- material can only be moved between the rows (bays) in the facility with the fixed patch trolleys; and
- no physical changes to the workshop infrastructure are allowed, thus
  - no repositioning of doors are allowed;
  - no extra doors will be built; and
  - the overhead cranes are fixed in the current bays.

Figure 3.4 below indicates the measurements of the fabrication facility in the standard measure of distance $[m]$. The facility consists of two rows, each of $9m$ in width, which is its bays and a horizontal aisle of $1m$ in width within each row. The facility is $40m$ wide in the vertical (y) dimension and $250m$ in length in the horizontal (x) dimension. The sum of the vertical widths of departments placed on one side of an aisle can not exceed $9m$, as indicated by the visual representation below. The horizontal length of the facility is subdivided into three segments of various lengths by the vertical driving zones and the walkway in the facility. The figure below also indicates the horizontal length limit of the sum of the lengths of departments placed in the different segments of the workshop.

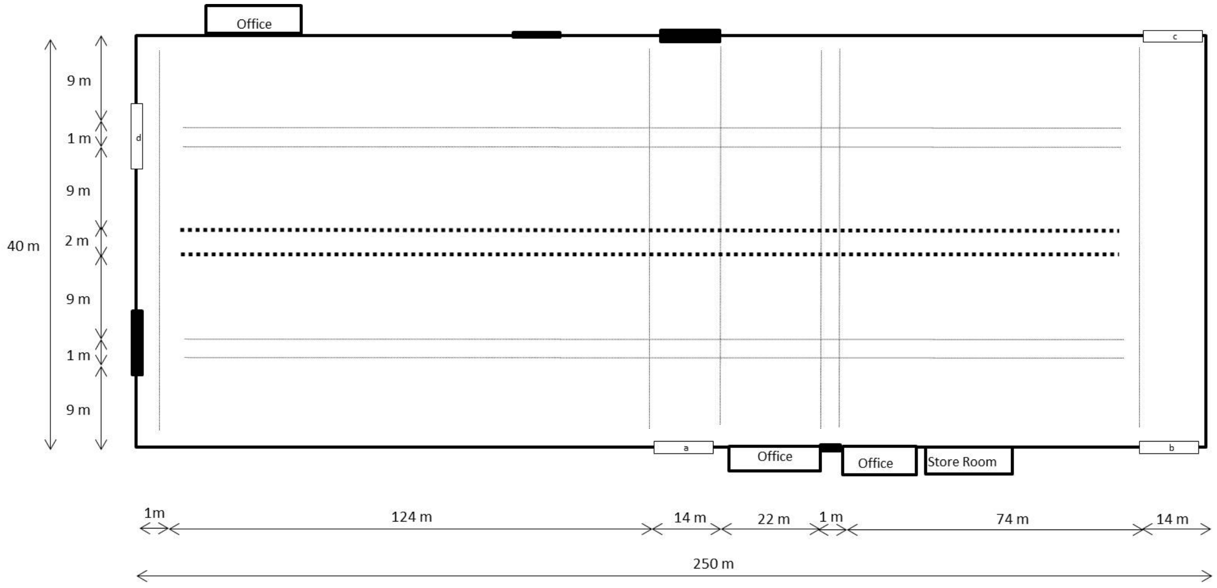

Figure 3.4: Physical Workshop Dimensions

3.2.2 Input data analysis

The most relevant and important input data used in the development of the facility layout alternatives is the physical workshop and workstation measurements. Table J.1 and J.2, included in Appendix J, lists the physical measurements of the workstations and the current measurements of the storage areas.

The from-to chart represented in Figure K.1, included in Appendix K, was used as an input to alternative facility layout developments to order the closeness of departments in the facility layout design, based on the relationship between sets of functional departments.

The relationship matrix represented in Figure L.1, included in Appendix L, was constructed from the material flow frequencies between departments in the from-to matrix and the criteria listed below in Table 3.1 as suggested by Tompkins et al. (2010). The important adjacencies are indicated on the relationship matrix with red, orange and yellow in descending order of importance.

Importance Index	Importance Description	Material Flow Frequency Range
A	Absolutely Important	75 - 100%
E	Especially Important	50 - 74%
I	Important	21 - 49%
O	Ordinary Important	11 - 20%
U	Unimportant	0 -10%

Table 3.1: Relationship Matrix Criteria

3.2.3 Assumptions

The assumptions the layout alternatives' construction were based on are as follows:

- workstations and storage areas that belong to the same processes can be modelled as a single functional department;
- functional department areas have a length in the horizontal direction and a width in the vertical direction;
- the measurements of the storage areas are not fixed, and can thus be changed from the current sizes;
- the walkways and driving zones are fixed and can't be adjusted, as these areas are right in front of the relevant doors in the facility and these doors are fixed;
- the facility has two rows which are the different bays in the workshop; and
- a department can be placed on both sides of an aisle in a row.

3.2.4 Development of facility alternatives

Different facility layout types were developed to test the effect of these layout types on the fabrication process in the simulation model. To improve the the physical layout of the fabrication process supplementary improvement opportunities were considered to assist in reducing the non-value adding time that forms part of the production time of items and leads to the imbalanced production time problem the company is faced with.

Supplementary improvement opportunities

Currently the company makes use of three quality control inspections. These quality inspections are done at the assembling and welding processes and at the dispatch area. Process observation and data analysis showed that 35% of defects are only identified at the dispatch quality inspection. This 35% consists of 10% drilling, 8% welding and 7% assembling defects, as can be seen on the reverse process of the from-to matrix represented in Figure K.1, included in Appendix K.

Improving the quality of the assembling and welding inspections processes and adding a drilling quality inspection process will ensure that only items that have no quality defects from the specific process enter the next production process. Although the actual quality inspection time will increase, it is expected that the overall production time of items will be positively affected. It is assumed that the increase in the time of inspections to improve the quality thereof are equal to the percentage reduction in defects missed at the specific quality inspections. It is assumed that the number of items that have to be sent back into the production process, due to defects missed by the process' quality inspections and only being identified at the dispatch quality inspection, will be reduced by 20% if the quality of the inspections improves. Reducing the number of items that are sent back, or eliminating the reverse process, will result in a reduction of the production time of items as the needless material moving time will be eliminated.

Currently the workshop focusses on minimum idle time of workstations. This causes the production process sequence to be bypassed and results in items being moved forward and backward between processes, which increases the material moving and production time of items. It is expected that overall production time of items will be reduced, although resource utilization will reduce, if the workshop adheres to a fixed production process sequence. The fixed sequence will reduce the non-value adding time of extensive material movement in the workshop. The fixed path makes it easier to improve the facility layout as it reduces the material moving path possibilities. A fixed process sequence is possible as most items require the same processes to be executed. Figure 3.5 below represents the suggested fixed production process sequence, where the green arrows indicate the forward flow and the red arrows the reverse flow in the production process.

The vertical and horizontal fixed path trolleys should be relocated to the optimal position in the workshop, based on the specific alternative layout's requirements. The trolleys can be moved as the rails are only fixed to the ground by means of bolts. The horizontal trolleys' direction should be changed to be vertical to assist with the material movement between the rows in the facility. It is feasible to change the horizontal direction of the two trolleys to a vertical direction as these trolleys currently have a low utilization as most material are moved in the x-direction with the overhead cranes. Changing the direction of these trolleys will result in having four vertical trolleys that can be used to move material between the bays in the workshop. This reduces the time of having to move material to the central horizontal position of the workshop and from there to the desired destination.

Items that are found to be defective in terms of assembling at the final quality check, should only be sent back to a specific allocated assembling workstation. This allocated assembling station should be the one closest to the dispatch area. This will ensure that the minimal time possible is spent to move the item back up in the reverse process line.

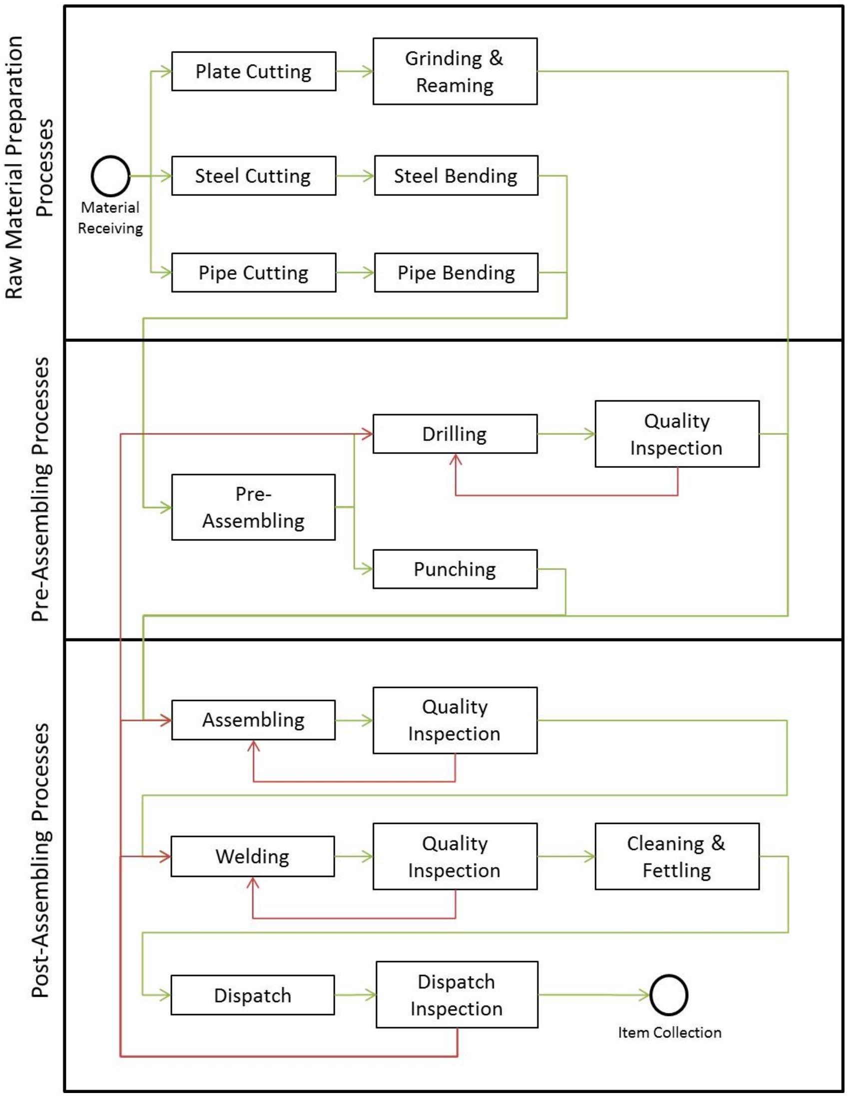

Figure 3.5: Suggested Fixed Production Process Sequence

Alternative layouts

A process, product and combinational layout alternative was developed by means of the systematic layout planning (SLP) procedure as discussed in Section 2.3.

A U-shaped production line was considered for the process and product layouts as it minimizes material handling with the entering and exit area of the material being at the same point in the workshop. A U-shape layout also increases flexibility in work assignments and permits increased communication (Stevenson, 2012).

A process layout was considered for the fabrication workshop as job shop processing is used where all work is done on orders received and items based on detailed design drawings are fabricated in small quantities. In the process layout alternative, the functional departments are grouped together that perform similar activities. The fabrication processes of Louwill are grouped into the pre-activities on raw material, hole-making processes, assembling, welding and post-cleaning activities. Figure 3.6 below represents the developed process layout alternative modelled for the current and improved process of the workshop.

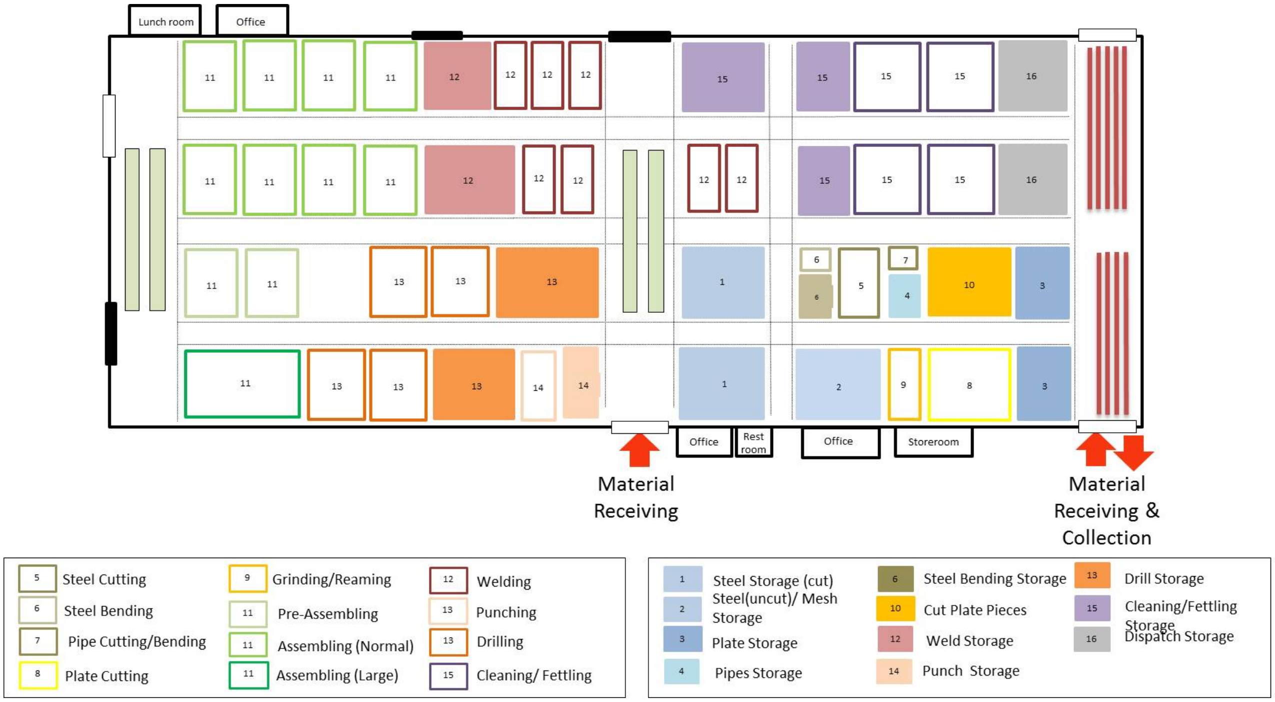

Figure 3.6: Process Facility Layout Alternative

A product layout was considered for the fabrication workshop as most items follow the same production process sequence. According to Stevenson (2012) a product layout assists in rapid flow of large volumes through a production line. Two product layout alternatives were developed for the workshop to address the current and suggested production process sequence. The product layout considered for the current process sequence is depicted in Figure 3.7 and that for the suggested fixed process sequence in 3.8.

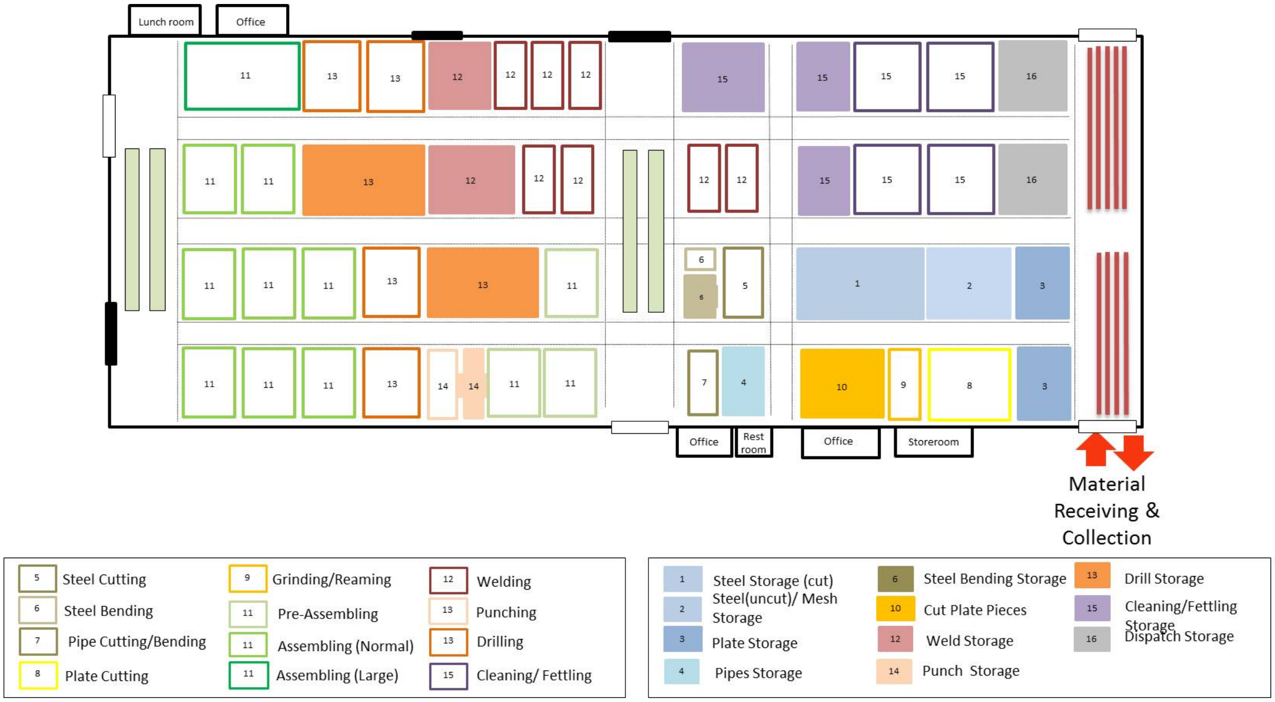

Figure 3.7: Product Facility Layout Alternative for Current Process Sequence

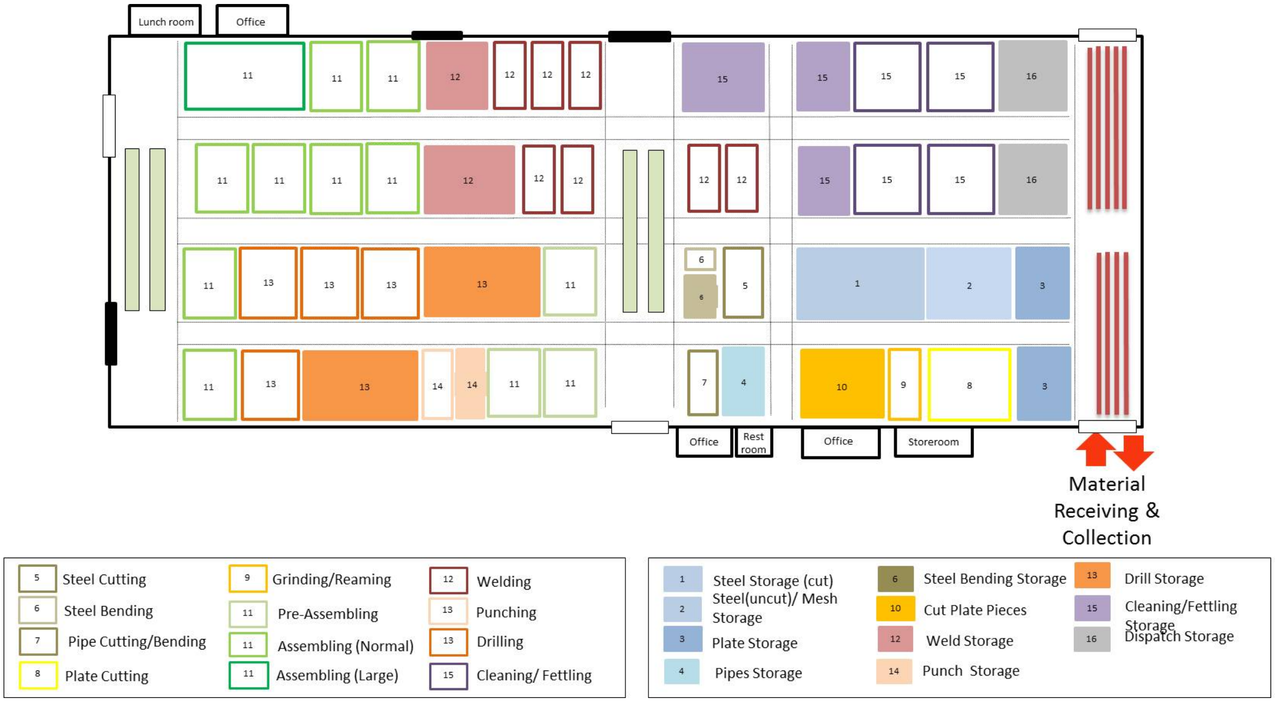

Figure 3.8: Product Facility Layout Alternative for Suggested Fixed Process Sequence

The product and process layouts represent the two ends of the continuum. Louwill's manufacturing operations depict characteristics of an assembling line as well as job shop processing and therefore a combinational layout was considered, as it captures advantages of both the process and product layouts. The combinational facility layout which was considered for the fabrication workshop is a combination of a process and product layout. The developed combinational layout is shown in Figure 3.9. The combinational layout was only used to model the current process sequence.

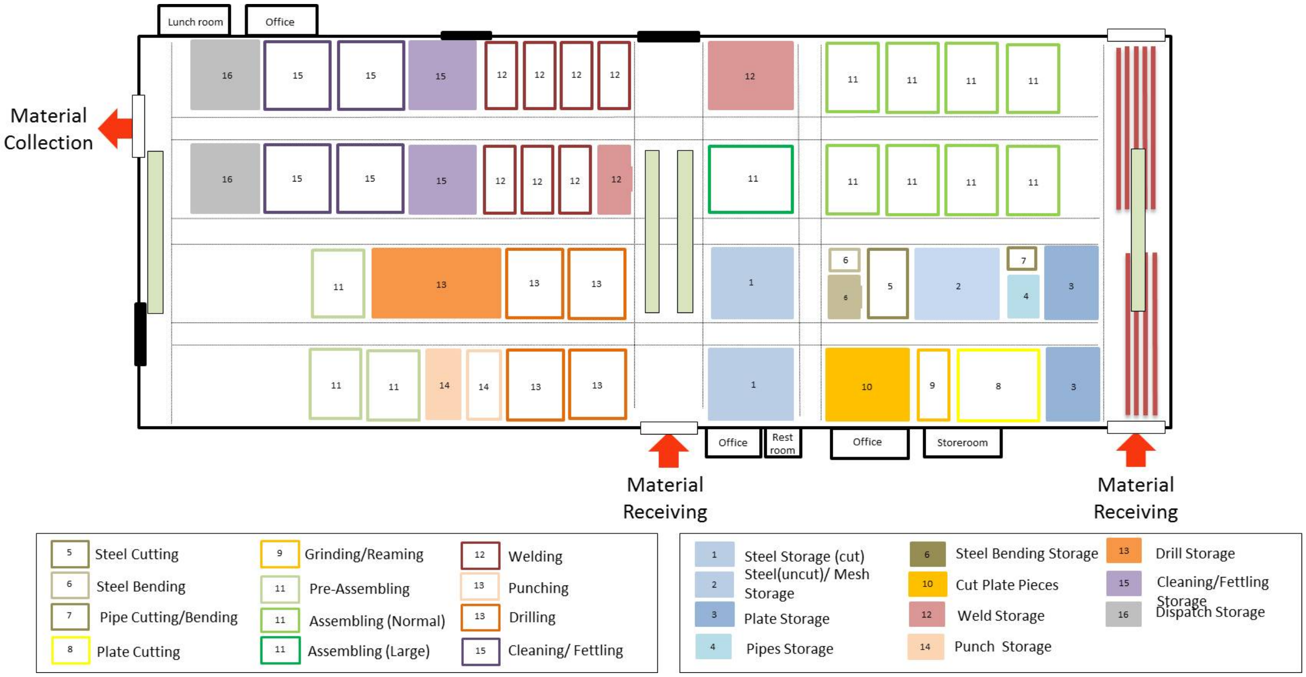

Figure 3.9: Combinational Facility Layout Alternative

3.3 Facility alternative selection algorithm development

The variables used throughout the PSI methodology for this project are as follows:;

→ Y_i = the set of facility alternatives for $i \in 1, 2, 3, \ldots, 7$, where

$$i \in \begin{cases} 1 = & \text{current layout with current process sequence;} \\ 2 = & \text{process layout with current process sequence;} \\ 3 = & \text{product layout with current process sequence;} \\ 4 = & \text{combinational layout with current process sequence;} \\ 5 = & \text{current layout with suggested fixed process sequence;} \\ 6 = & \text{process layout with suggested fixed process sequence; and} \\ 7 = & \text{product layout with suggested fixed process sequence.} \end{cases}$$

→ C_j = the set of facility layout design decision attributes for $j \in 1, 2, 3, 4$, where

$$j \in \begin{cases} 1 = & \text{total processing time;} \\ 2 = & \text{re-processing time;} \\ 3 = & \text{non-value adding time; and} \\ 4 = & \text{total time spend in the workshop.} \end{cases}$$

The layout design attributes used in the selection methodology are all non-beneficial, thus the smaller the value of the attribute the better. The attribute values are calculated as the average values of the multiple runs, each for a ten year period, for each tested facility alternative.

The total process time is the sum of the actual time spent by an item in its production processes. The smaller the actual production time is the more balanced will the production times of items be in the workshop.

The re-process time of an item is the actual time spent by an item in processes to correct defects. The re-process time is used as a decision attribute as it increases the actual time an item spends in the workshop contributing to the imbalanced production time problem.

The non-value adding time attribute is made-up of all the non-production times of an item in the workshop. This time consists of the time an item spends in buffer queue areas and moving around between functional departments. A small non-value adding time indicates a good process and material flow which results in shorter actual time spent by an item in the workshop and more balanced actual and planned production times.

The total time an item spends in the workshop is measured from when the item is issued to fabrication up to when the item successfully completes its final dispatch quality inspection. The shorter the total time spent in the workshop, the more balanced the planned and actual production time of items.

Chapter 4

Results

The characteristics, processes and production times of items were obtained as outputs from the simulation model. Each alternative in the simulation model was run five times, each for a ten year period, to obtain realistic measured outputs for each alternative. These outputs were used to calculate the average values of the design selection attributes for each of the facility alternatives, to use as inputs to the Preference Selection Index (PSI) methodology.

The current facility layout of Louwill was modelled in the simulation to obtain design selection attributes for the base case, to which the facility alternatives' selection attribute outputs could be measured against to analyse improvements.

The facility alternatives mentioned in Section 3.3 were constructed in the simulation model and compared to one another with the Preference Selection Index (PSI) discussed in Section 2.3. The PSI methodology was used to identify the best facility alternative for the fabrication facility of Louwill among the different alternatives tested. The actual PSI execution is included in Appendix M. The facility alternatives, in order of preference, are listed below, in ascending order of the design selection index value (Ω_i):

1. Product layout with the suggested fixed process sequence.
2. Process layout with the suggested fixed process sequence.
3. Current layout with the suggested fixed process sequence.
4. Product layout with the current process sequence.
5. Current layout with the current process sequence.
6. Combinational layout with the current process sequence.
7. Process layout with the current process sequence.

This indicates that the product layout with the suggest fixed process sequence is the best facility alternative among the alternatives tested.

The facility alternatives listed below were compared to the base case to analyse the effects of different improvement opportunities:

- product layout with the current process sequence;
- current layout with the suggested fixed process sequence; and
- product layout with the suggested fixed process sequence.

The product layout alternative with the current process sequence was used in the comparison as it is the best facility layout to use if the process sequence remains unchanged. This alternative were used to analyse the effect that pure layout improvement, without the adoption of the suggested fixed process sequence, has on the attribute measures. The current layout alternative with the suggested fixed process sequence was used in the comparison to analyse the effect that pure improvement of the process sequence, without changing the facility layout, has on the attribute measures. The product layout alternative with the suggested fixed path process sequence was used in the comparison as it is the best facility layout to use if the suggested fixed process sequence is adopted. This alternative was used to analyse the effect that process improvement, along with changing the facility layout, has on the attribute measures. The results of the comparison of these alternatives to the base case, thus the current facility layout and process sequence are depicted in Table 4.1. The table indicates the percentage reduction in average time per unit for the facility alternatives compared to the base case, for each selection attribute.

	% Improvement		
Selection Attributes	**Pure Layout**	**Pure Process**	**Layout & Process**
Total Processing Time	1%	11%	12%
Re-processing Time	2%	34%	37%
Non-Value Adding Time	-	10%	13%
Total Time Spend in the Workshop	-	12%	14%

Table 4.1: Effects of the Facility Alternatives on the Attribute Measures

This indicates that purely changing the layout within the fabrication facility of Louwill will have a negligibly small time improvement impact on the attribute measures. The analysed improvements in this table indicate that the supplementary improvement opportunities suggested in Subsection 3.2.4 could ensure a large improvement for the fabrication facility if implemented. The improvement results of the pure process improvement alternative, and the process and layout improvement alternative, are closely related.

As part of the comparison analysis the average hours per tonne of the different item categories are calculated and compared to the base case. Table 4.2 indicates the percentage reduction in the average production hours per tonne for the different item categories for the facility alternatives compared to the base case. The results indicates that implementing the suggested supplementary improvement opportunities and changing the current layout, results in the largest reduction in the production time percentages. The overall percentage reduction in the the average hours per tonne for the different facility alternatives is calculated as:

$$OverallReduction_{comparedlayouts} = \sum_{j=1}^{9} (\%Contribution_j \times \%Improvement_j) \tag{4.1}$$

			% Improvement		
Steel Type	**Detail Type**	**% Contribution to Demand**	**Pure Layout**	**Pure Process**	**Layout & Process**
Light Steel	Little Design Detail	8%	5%	4%	8%
	Fair Design Detail	6%	5%	8%	13%
	Specific Design Detail	19%	4%	9%	13%
Medium Steel	Little Design Detail	3%	4%	9%	13%
	Fair Design Detail	25%	3%	9%	12%
	Specific Design Detail	5%	3%	10%	13%
Heavy Steel	Little Design Detail	23%	3%	10%	13%
	Fair Design Detail	4%	3%	10%	13%
	Specific Design Detail	6%	3%	10%	13%
Overall reduction in $Hours/Tonne$			3%	9%	12%

Table 4.2: Effects of the Facility Alternatives on the Average Production Time of Items

The average hours per tonne of the different item categories are compared to the estimated production time of items, which is used to calculate the planned production time of items and the monthly capacity

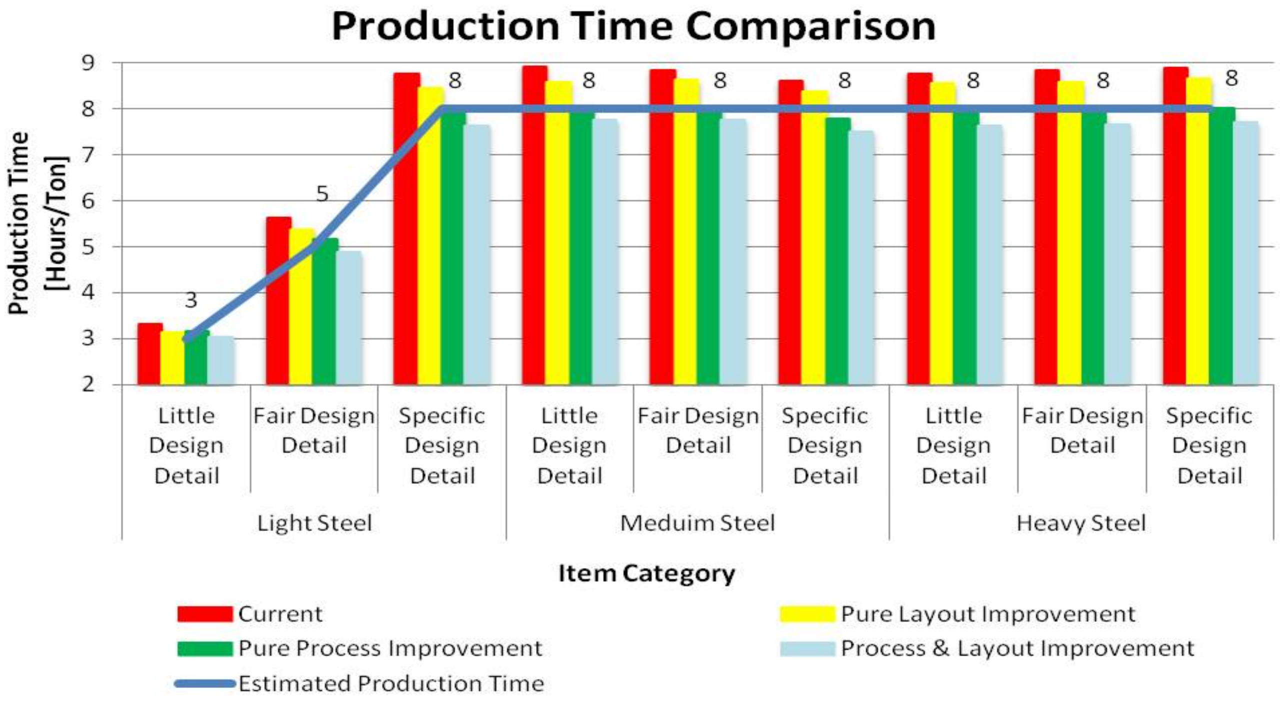

Figure 4.1: Production Time Comparison

of the workshop. The average production time [$hours/tonne$] of an item is analysed and compared to the estimated production time (E_{ij}) of the type of item to analyse the improvement of the system. Figure 4.1 analyses the production times of the compared improvement opportunities to the estimated production time, indicated with the line graph, for each item category. This graph visually depicts that the current production hours per tonne, and that of the pure layout alternative, are larger than the estimated production times. Table 4.3 indicates that only the layout and process improvement alternative's production times are all less that the estimated production times for all the item categories. This concludes that by changing the fabrication facility's layout to a product layout and improving the current process will address the imbalance production time problem.

		$[Hours/Ton]$				
Steel Type	**Detail Type**	**Estimated Time**	**Current Time**	**Pure Layout**	**Pure Process**	**Layout & Process**
Light Steel	Little Design Detail	3	3.31	3.31	3.17	3.04
	Fair Design Detail	5	5.62	5.37	5.18	4.87
	Specific Design Detail	8	8.78	8.47	7.98	7.65
Medium Steel	Little Design Detail	8	8.93	8.60	8.09	7.76
	Fair Design Detail	8	8.86	8.63	8.03	7.77
	Specific Design Detail	8	8.61	8.39	7.79	7.51
Heavy Steel	Little Design Detail	8	8.78	8.85	7.91	7.63
	Fair Design Detail	8	8.84	8.60	7.96	7.67
	Specific Design Detail	8	8.91	8.67	8.02	7.72

Table 4.3: Comparison of the Average Production Time of Items to the Estimated Production Time

Chapter 5

Recommendations

Based on the results of the PSI methodology and the comparison study discussed in Chapter 4, it is recommended that Louwill Engineering changes their current process and the layout of the fabrication facility.

It is recommended that the fabrication facility's layout be changed to the product layout depicted in Figure 3.8 in Sub-section 3.2.4 of Chapter 3. The product layout is U-shaped with the entering and exit area of the material positioned at the same point to minimize material handling in the workshop and increase flexibility in work assignments. The product layout will assist in rapid flow of large volumes of items through the production process. The recommended dimensions of workstations, storage areas and buffer queue areas are depicted in Table N.1 and Table N.2, included in Appendix N. Adopting the recommended product layout for the fabrication workshop will require changing the position and direction of flow of the two vertical trolleys currently positioned horizontally in the workshop. The costs involved in changing the current layout are as follows:

- downtime of the workshop; and
- actual movement of workstations:
  - labour;
  - moving equipment; and
  - repainting floor areas for workstations.

It is suggested that the fabrication workshop adopts the fixed process sequence depicted in Figure 3.5 in Sub-section 3.2.4 of Chapter 3 to improve the current production process. The fixed sequence of processes will reduce the non-value adding time of extensive material moving in the workshop by reducing an item's material moving path possibilities. The fixed process sequence is possible as most items require the same processes to be executed.

To reduce the reverse process movement of items it is recommended that the company improves the quality of the assembling and welding quality inspections and adds a quality inspection after the drilling process to ensure that less items are unnecessarily moved forward and backward between processes.

If the company decides not the change the layout of the fabrication workshop, it is recommended that they still implement the supplementary improvement opportunities. Only implementing the improvement opportunities and changing the current process to the suggested fixed process sequence will yield great improvement for the company.

The principle objective is to transform the current process to an in-control process were the actual production time of items are smaller or equal to their planned production time. This will contribute to Louwill meeting promised lead times and planned workshop capacity; without incurring extra costs or sacrificing customer satisfaction. Implementing the recommendations will address the imbalance in the production times of items and will ensure that items are delivered on-time to succeeding companies in the inter-company supply chain and to sites.

Chapter 6

Conclusion

Louwill Engineering forms part of an inter-company supply chain. The company is currently faced with an imbalance in the planned and actual production time of items which not only affects the company, their planning and costs, but also affects the job scheduling of succeeding companies as this scheduling is done based on promised lead times from the fabricator. Three major causes of the imbalanced production time problem was identified of which this project addressed the zig-zag material flow in the fabrication workshop.

The fabrication process of Louwill was modelled as a Discrete Event Simulation in Anylogic to test different facility alternatives and obtain measures for the selection attributes of the PSI methodology as outputs. The facility alternatives tested consisted of process, product and combinational layouts in combinations with different process alternatives. The PSI methodology was used to select the best facility alternative, among the tested alternatives, and a comparison study was done to analyse the effect of different improvement strategies.

A product layout and the suggested fixed process sequence is recommended to the company based on the results of the PSI methodology. If implemented and adopted these recommendations will result in a reduction of the actual time an item spends in the workshop contributing to balancing the actual and planned production time of items.

The comparative study concludes that the process is the largest factor impacting the production, moving and buffer times of items. Changing only the layout of the fabrication facility will result in negligibly small time improvements, whereas changing only the process and adopting the supplementary improvement opportunities will result in noticeable time improvements. Changing the layout and improving the process will yield the most satisfactory time improvement results of the three improvement possibilities compared, leading to balanced planned and actual production time of items in the fabrication facility.

An opportunity exists for future work on this project as only one of the tree major causes of the identified imbalance production time problem was addressed in this project. Addressing the high levels of work-in-process inventory that exists due to an imbalance in the work and time load placed on different functional departments and the non-aligned prioritizing of work between project management and the workshop will result in a more balanced state of the planned and actual production times of items. This balanced state will be achieved through a reduction in the actual production time (A_{ij}) of items. The literature review concluded that line balancing and job scheduling are possible research fields for further improvement.

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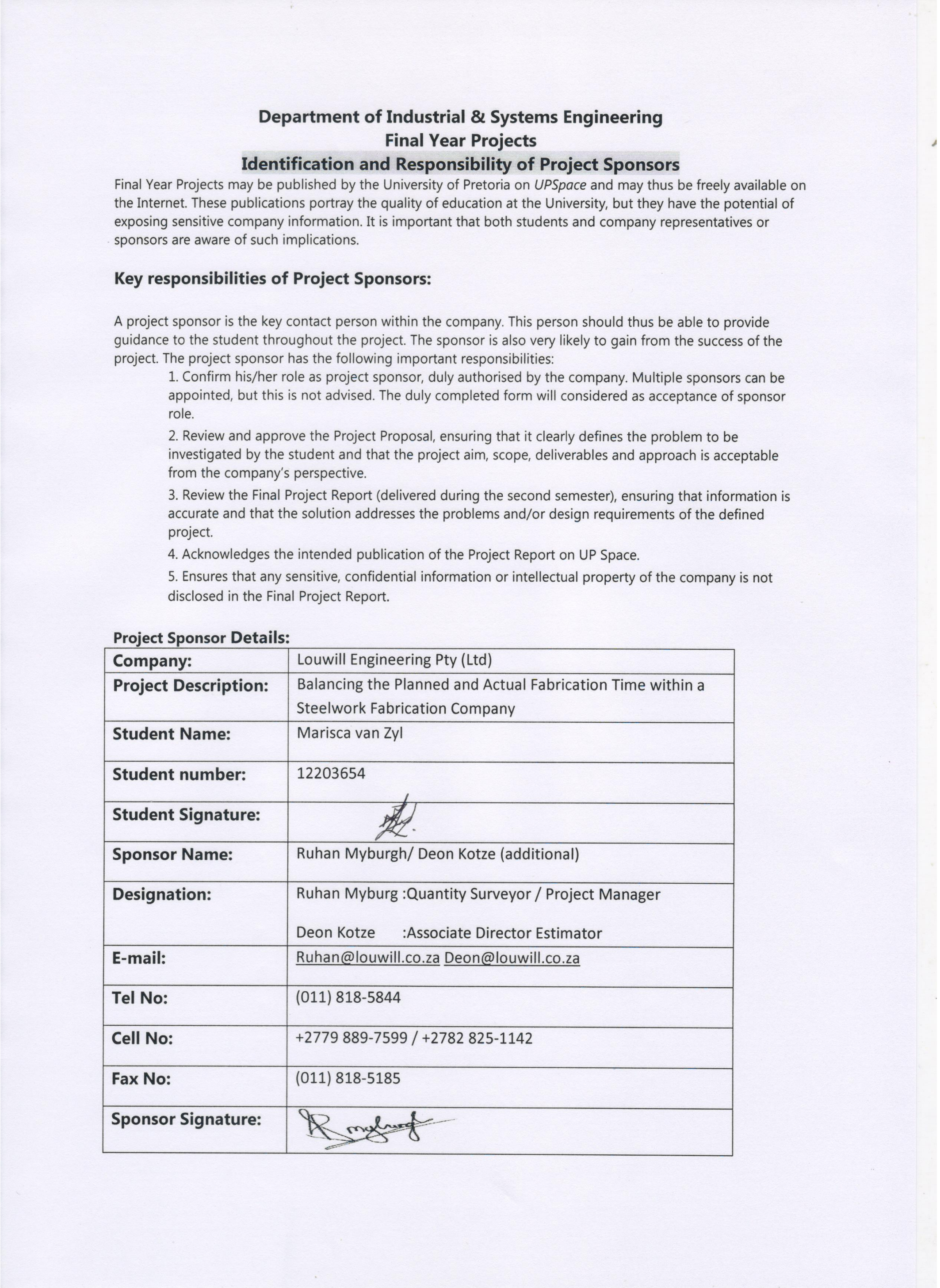
Appendix A

Industry sponsorship form



Department of Industrial & Systems Engineering
Final Year Projects
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Key responsibilities of Project Sponsors:

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

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

Project Sponsor Details:

Company:	Louwill Engineering Pty (Ltd)
Project Description:	Balancing the Planned and Actual Fabrication Time within a Steelwork Fabrication Company
Student Name:	Marisca van Zyl
Student number:	12203654
Student Signature:	
Sponsor Name:	Ruhan Myburgh/ Deon Kotze (additional)
Designation:	Ruhan Myburg :Quantity Surveyor / Project Manager Deon Kotze :Associate Director Estimator
E-mail:	Ruhan@louwill.co.za Deon@louwill.co.za
Tel No:	(011) 818-5844
Cell No:	+2779 889-7599 / +2782 825-1142
Fax No:	(011) 818-5185
Sponsor Signature:	

Appendix B

Current process flow in the workshop

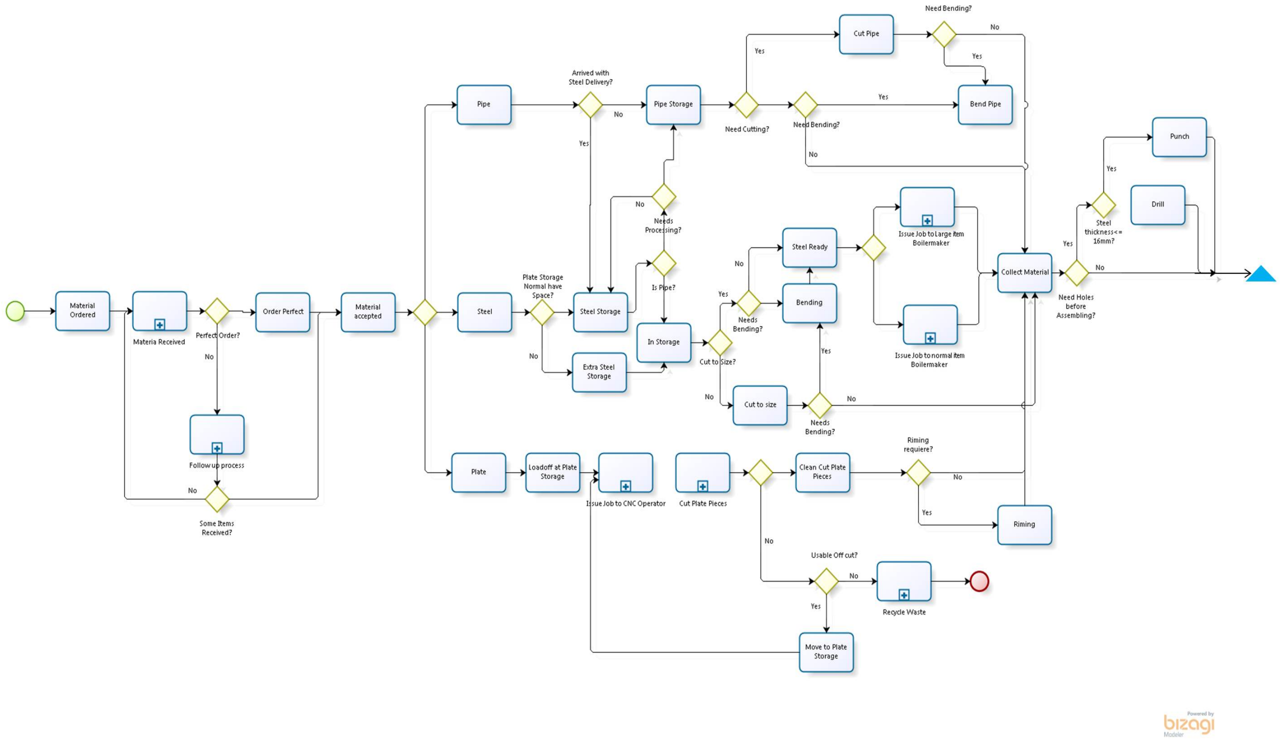


Figure B.1: Current Pre-Assembling Process Flow in the Workshop

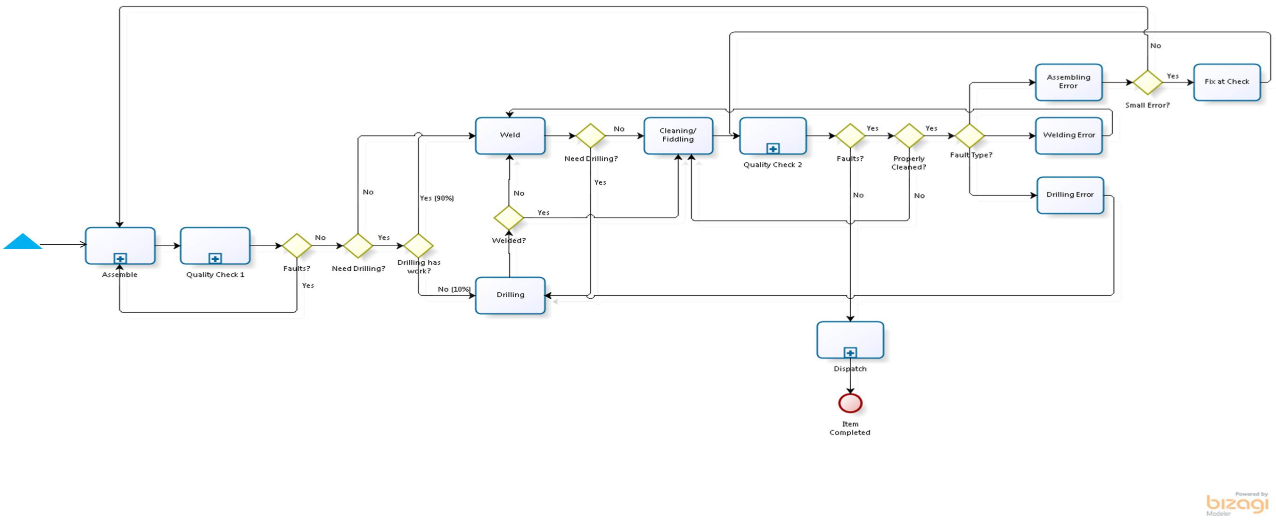


Figure B.2: Current Post-Assembling Process Flow in the Workshop

Appendix C

Current material flow in the workshop

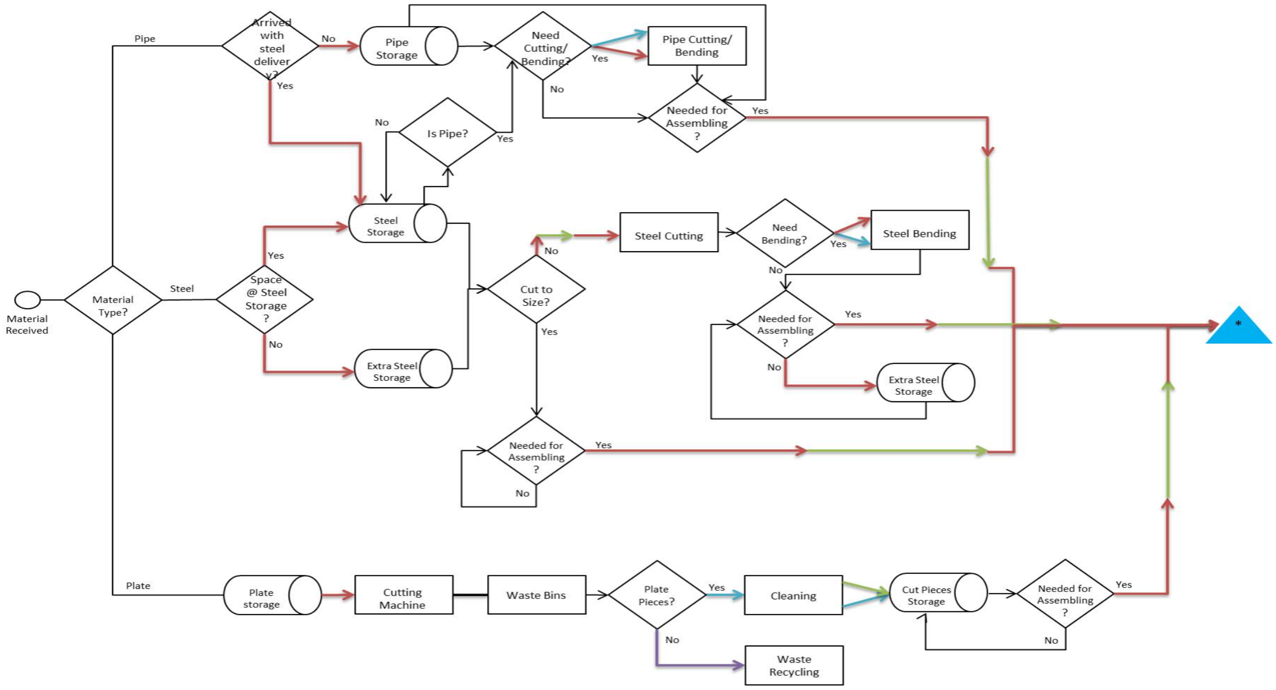


Figure C.1: Current Pre-Assembling Material Flow in the Workshop

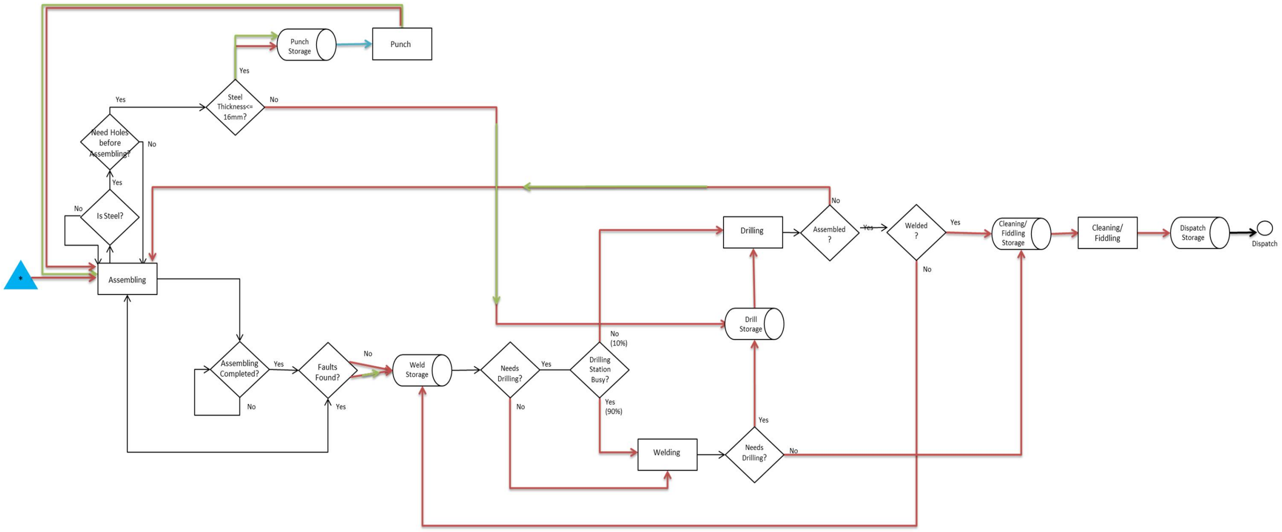


Figure C.2: Current Post-Assembling Process Material Flow in the Workshop

Appendix D

Demand Distribution

Steel Type	ST %	Detail Type	DT %	Item Type	IT %	Material Used
Light Steel	76	Little Design Detail	24	Platforms	15	Steel & Plate
				Structures	35	Steel & Plate
				Transfer Towers	45	Steel & Plate
				Miscellaneous	5	Steel
		Fair Design Detail	18	Overland Conveyor Stringer Modules	95	Steel & Plate
				Miscellaneous	5	Steel
		Specific Design Detail	58	Cat Ladders	2	Steel & Plate
				Screens	3	Steel & Plate & Mesh
				Guards	11	Steel & Plate & Mesh
				Plate Work	11	Steel & Plate
				Gantry	18	Steel & Plate
				Support steel	31	Steel & Plate
				Graded Stringers	18	Steel & Plate & Pipes
				Miscellaneous	5	Steel & Plate & Mesh
Medium Steel	19	Little Design Detail	9	Piping and Ducting Support Structures	95	Plate
				Miscellaneous	5	Steel & Plate
		Fair Design Detail	76	Storage Shed Structures	9	Steel & Plate
				Trestles	32	Steel & Plate & Pipes
				Moving Head	54	Steel & Plate
				Miscellaneous	5	Steel
		Specific Design Detail	16	Counter Weight Tower	95	Steel & Plate
				Miscellaneous	5	Steel
Heavy Steel	5	Little Design Detail	69	Structural Rails	35	Steel
				Crawl Beams	61	Steel
				Miscellaneous	5	Steel & Plate
		Fair Design Detail	13	Portal Type Building Structures	95	Steel & Plate & Pipes
				Miscellaneous	5	Steel & Plate
		Specific Design Detail	19	Mining Headgear Structures	32	Steel & Plate & Pipes
				Plate Girders	63	Plates
				Miscellaneous	5	Steel & Plate

Table D.1: Demand Distribution of Item Types and Categories

Appendix E

Item Issue to Fabrication Frequency

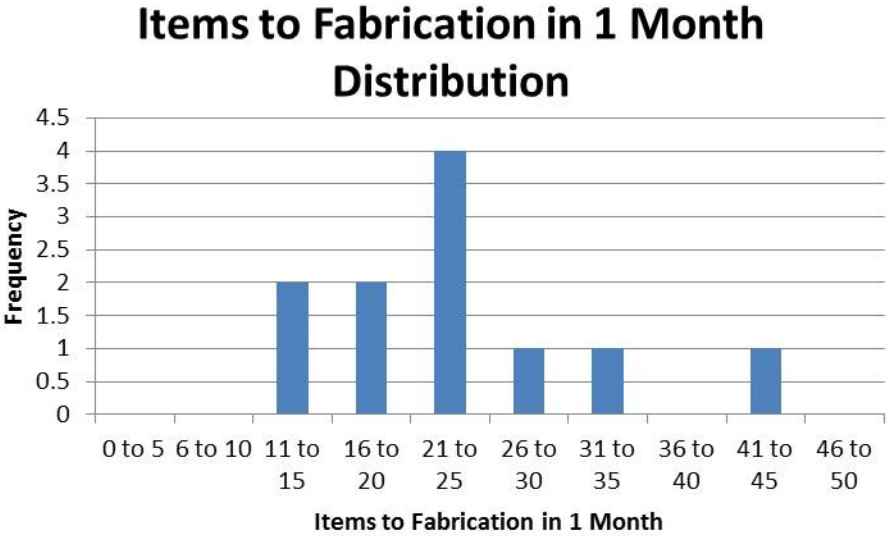


Figure E.1: Average items Issued to Fabrication per Month

Figure E.2: Average items Issued to Fabrication over 12 Months

Appendix F

Process Times

			Mean Production Time A_{ij} [$hours$]			
Steel Type	**Detail Type**	**Item Type**	**Assembling**	**Drilling / Punching**	**Welding**	**Cleaning & Fettling**
Light	little	Structures	8	2	8	1
		Platforms	8	2	8	1
		Transfer Towers	8.5	2	7	1
		Miscellaneous	7	2	7	2
	fair	Overland Conveyor Stringer Modules	12	6	10	4
		Miscellaneous	10	6	9	4
	specific	Gantry	10	6	12	3
		Graded Stringers	18	6	10	3
		Screens	18	4	10	2
		Guards	16	4	12	2
		Support Steel	18	6	8	2
		Guards l	18	4	10	2
		Support Steel	18	4	10	2
		Plate Work	20	0	16	8
		Cat Ladders	35	8	40	2
		Miscellaneous	18	6	10	6
Medium	little	Piping & Ducting Support Structures	8	4	6	2
		Miscellaneous	6	5	5	2
	fair	Storage Shed Structures	8	2	6	2
		Moving Head	10	6	6	2
		Trestles	8	4	6	2
		Miscellaneous	6	4	8	2
	specific	Counter Weight Tower	10	6	6	2
		Miscellaneous	8	6	8	2
Heavy	little	Crawl Beams	6	4	4	3
		Structural Rails	6	3	4	3
		Miscellaneous	6	0	0	0
	fair	Portal Type Building Structures	7	2	5	2
		Miscellaneous	6	3	5	1
	specific	Plate Girders	3	6	12	3
		Mining Headgear Structures	7	2	5	2
		Miscellaneous	5	4	8	3

Table F.1: Mean Production Times of Items in Departments

Appendix G

Simulation model's item characterisation

Part-entity's Characterisation Parameters

Parameter Name	Description
parID	uniquely identify each item that goes through production
parSteelType	indicates the steel type the item belongs to, based on the demand distribution
parDetailType	indicates the detail type of the item, based on the demand distribution
parItemType	indicates the type of the item, based on the demand distribution
parRMType	used to group the items with the same raw materials and to create to correct raw materials in the simulation model
parRMColor	visually sets the color of the entity based on its raw material group
parRMSpec	sets the specific raw material type a copy of an item represents
parWeight	sets the weight of an item randomly, based on the item's specific weight distribution

Table G.1: Item Characterisation Parameters

Part-entity's Process Time Parameters

Parameter Name	Description
parPlateCutting	sets the processing time of cutting a plate
parPreCleaning	sets the time the plates spend in the pre-cleaning process
parSteelCutting	sets the processing time of cutting steel based on the weight of the item
parSteelBending	sets the processing time of bending steel based on the detail of the item
parPipeCutting	sets the processing time of cutting pipes based on the weight of the item
parPipeBending	sets the processing time of bending pipes based on the detail of the item
parAssembling	sets the processing time of assembling an item out of its raw material based on the item's specific assembly time distribution
parWelding	sets the processing time of welding an item based on the item's specific welding time distribution
parDrillingPunching	sets the processing time of drilling or punching an item based on the item's specific hole making process's time distribution
parCleaningFettling	sets the processing time of cleaning an item after fabrication based on the item's specific cleaning & fettling time distribution

Table G.2: Process Time's Parameters

Part-entity's Process Indicator Parameters

Parameter Name	Description
parProWelded	boolean value that is set as an entity completes the welding process, used to ensure an entity does not re-enter the welding process throughout its fabrication process
parProPunched	boolean value that is set as an entity completes the punching process, used to ensure an entity does not re-enter any of the hole making processes throughout its fabrication process
parProDrilled	boolean value that is set as an entity completes the punching process, used to ensure an entity does not re-enter any of the hole making processes throughout its fabrication process
parNeedCut	boolean value that indicates if the raw material; steel are uncut
parReWeld	boolean value that is set if an entity needs to be re-welded in the reverse process, use to ensure that the item is only welded again and does not enter any other process lines or re-enters the reverse process
parReDrill	boolean value that is set if an entity needs to be re-drilled in the reverse process, use to ensure that the item is only welded and drilled again and does not enter any other process lines or re-enters the reverse process
parReAss	boolean value that is set if an entity needs to be re-assembled in the reverse process, use to ensure that the item is only re-assembled and welded again and does not enter any other process lines or re-enters the reverse process

Table G.3: Process Indicator Parameters

Appendix H

Human resources allocation

			Human Resource Type															
		Number of Workstations	**Material Controller**	**Crane Operator**	**General Worker**	**Plate Cleaners**	**CNC Operator**	**CNC Assistant + C/O**	**Boilermaker**	**Boilermaker Assistant + C/O**	**Radial/A Drill Operator**	**Welders**	**Grinder Operator**	**Structural Steel Cleaner**	**Dispatch Inspector**	**Quality Inspectors**	**Welder Supervisor**	**Engineering Generalist**
			1	4	12	2	1	1	13	13	6	8	7	8	2	2	1	1
Functional Departments	**Material Receiving**		1	1	2													
	Plate Cutting	1					1	1										
	Pipe Cutting	1		1	2													
	Pipe Bending	1	1	2														
	Grinding/ Reaming	2				2												
	Steel Cutting	1			2													
	Steel Bending	1			2													
	Assembling-Normal	11							1	1						1		
	Assembling-Large	1							1	1						1		
	Punching	2		1							1							
	Welding	7		1								1-3					1	
	Drilling	4		1							1							
	Cleaning and Fettling	4		1									1-4	1-4		1		
	Dispatch	1		1	4										1			

Table H.1: Human Resources Allocation

Appendix I

Workshop shifts

	Shift Schedule for Mon and Wed			
	Start Time	End Time	Working ?	Hours $[hours]$
Toolbox Talk	07 : 00	07 : 15	No	00 : 15
Working	07 : 15	09 : 00	Yes	01 : 45
Tea Time	09 : 00	09 : 15	No	00 : 15
Working	09 : 15	12 : 00	Yes	02 : 45
Lunch	12 : 00	12 : 30	No	00 : 30
Working	12 : 30	15 : 00	Yes	02 : 30
Tea Time	15 : 00	15 : 15	No	00 : 15
Working	15 : 15	16 : 00	Yes	00 : 45
	Total Shift Duration			09 : 00
	Working Hours per Shift			07 : 45

Table I.1: Shift Schedule of the Workshop for Monday and Wednesday

	Shift Schedule for Tue and Thu			
	Start Time	End Time	Working ?	Hours $[Hours]$
Working	07 : 00	09 : 00	Yes	02 : 00
Tea Time	09 : 00	09 : 15	No	00 : 15
Working	09 : 15	12 : 00	Yes	02 : 45
Lunch	12 : 00	12 : 30	No	00 : 30
Working	12 : 30	15 : 00	Yes	02 : 30
Tea Time	15 : 00	15 : 15	No	00 : 15
Working	15 : 15	16 : 00	Yes	00 : 45
	Total Shift Duration			09 : 00
	Working Hours per Shift			08 : 00

Table I.2: Shift Schedule of the Workshop for Tuesday and Thursday

	Shift Schedule for Friday			
	Start Time	End Time	Working ?	Hours $[Hours]$
Toolbox Talk	07 : 00	07 : 15	No	00 : 15
Working	07 : 15	09 : 00	Yes	01 : 45
Tea Time	09 : 00	09 : 15	No	00 : 15
Working	09 : 15	13 : 00	Yes	03 : 45
	Total Shift Duration			06 : 00
	Working Hours per Shift			05 : 30

Table I.3: Shift Schedule of the Workshop for Friday

Appendix J

Physical and current measurements

		Measurement $[m]$	
Workstation Name	**Number of Workstations**	**Workstation Length** (x)	**Workstation Width** (y)
Steel Cutting	1	14	9 Woensdag die 28ste
Steel Bending	1	10	3
Pipe Cutting & Bending	1	10	3
Plate Cutting	1	23	9
Grinding & Reaming	1	10	9
Assembling			
Normal Assembling	3	12	9
	8	16	9
Large Assembling	1	19	9
Welding	7	10	9
Drilling	4	16	9
Punching	1	3	3
Cleaning & Fettling	4	18	9

Table J.1: Physical Workstation Measurements

		Measurement $[m]$	
Storage Area Name	**Number of Storage Areas**	**Storage Area Length** (x)	**Storage Area Width** (y)
Steel Storage			
Normal/ Cut Steel	2	22	9
Large/ Uncut Steel	1	14	9
Plate Storage	2	14	9
Pipe Storage	1	10	5
Steel Cutting Storage	1	10	5
Plate Cut Pieces Storage	1	33	9
Weld Storage	1	15	9
Drill Storage	1	15	9
	1	6	9
Punch Storage	1	9	5
Cleaning & Fettling Storage	2	16	9
	1	15	9
Dispatch	2	18	9

Table J.2: Current Storage Area Measurements

Appendix K

From-to chart

To

From	Material Receiving	Steel Storage	Large Steel Storage	Plate Storage	Pipe Storage	Steel Cutting	Steel Bending	Pipe Cutting	Pipe Bending	Plate Cutting	Grinding & Reaming	Plate Cut Pieces Storage	Assembling	Welding	Drilling	Punching	Cleaning & Fettling	Dispatch	Collection
Material Receiving	-	0.45	0.10	0.40	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Steel Storage	-	-	-	-	-	0.05	0.20	-	-	-	-	-	0.60	-	0.10	0.05	-	-	-
Uncut Steel & Mesh Storage	-	-	-	-	-	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Plate Storage	-	-	-	-	-	-	-	-	-	1.00	-	-	-	-	-	-	-	-	-
Pipe Storage	-	-	-	-	-	-	-	0.60	0.20	-	-	-	0.20	-	-	-	-	-	-
Steel Cutting	-	-	-	-	-	-	0.50	-	-	-	0.50	-	-	-	-	-	-	-	-
Steel Bending	-	-	-	-	-	-	-	-	-	-	-	-	0.75	-	0.15	0.10	-	-	-
Pipe Cutting	-	-	-	-	-	-	-	-	0.30	-	-	-	0.70	-	-	-	-	-	-
Pipe Bending	-	-	-	-	-	-	-	-	-	-	-	-	1.00	-	-	-	-	-	-
Plate Cutting	-	-	-	-	-	-	-	-	-	-	1.00	-	-	-	-	-	-	-	-
Grinding & Reaming	-	-	-	-	-	-	-	-	-	-	-	1.00	-	-	-	-	-	-	-
Plate Cut Pieces Storage	-	-	-	-	-	-	-	-	-	-	-	-	0.80	-	0.10	0.10	-	-	-
Assembling	-	-	-	-	-	-	-	-	-	-	-	-	-	0.50	0.35	0.15	-	-	-
Welding	-	-	-	-	-	-	-	-	-	-	-	-	0.05	-	0.50	0.10	0.35	-	-
Drilling	-	-	-	-	-	-	-	-	-	-	-	-	0.15	0.20	-	-	0.65	-	-
Punching	-	-	-	-	-	-	-	-	-	-	-	-	0.35	0.55	-	-	0.10	-	-
Cleaning & Fettling	-	-	-	-	-	-	-	-	-	-	-	-	-	0.05	-	-	-	0.95	-
Dispatch	-	-	-	-	-	-	-	-	-	-	-	-	0.07	0.08	0.10	-	-	-	0.75
Collection	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

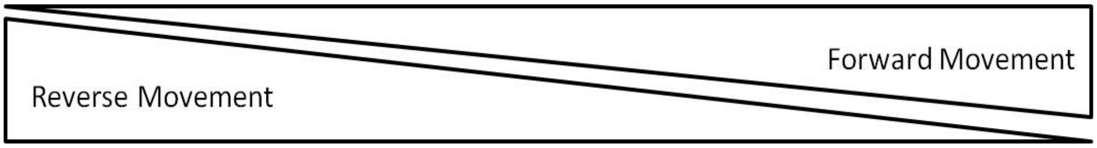
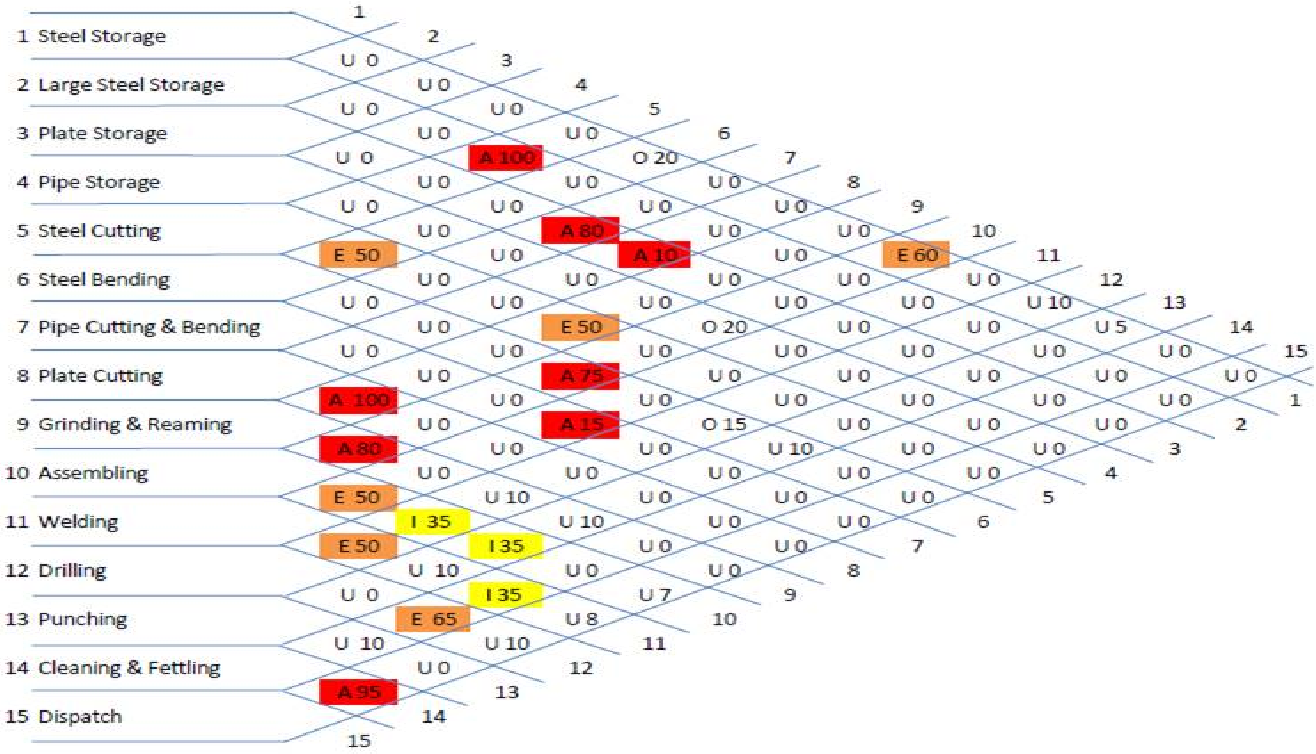


Figure K.1: From-To Chart of Material Flow Frequency

Appendix L

Relationship matrix



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1 Steel Storage		U 0	U 0	U 0	U 0	O 20	U 0	U 0	U 0	E 60	U 0	U 10	U 5	U 0	U 0
2 Large Steel Storage			U 0	U 0	A 100	U 0	U 0	U 0	U 0	U 0	U 0	U 0	U 0	U 0	U 0
3 Plate Storage				U 0	U 0	U 0	A 80	A 10	U 0	U 0	U 0	U 0	U 0	U 0	U 0
4 Pipe Storage					U 0	U 0	U 0	U 0	U 0	O 20	U 0	U 0	U 0	U 0	U 0
5 Steel Cutting						E 50	U 0	U 0	E 50	U 0	U 0	U 0	U 0	U 0	U 0
6 Steel Bending							U 0	U 0	U 0	A 75	U 0	O 15	U 10	U 0	U 0
7 Pipe Cutting & Bending								U 0	U 0	U 0	A 15	U 0	U 0	U 0	U 0
8 Plate Cutting									A 100	U 0	U 0	U 0	U 0	U 0	U 0
9 Grinding & Reaming										A 80	U 0	U 10	U 10	U 0	U 0
10 Assembling											E 50	I 35	I 35	U 0	U 7
11 Welding												E 50	U 10	I 35	U 8
12 Drilling													U 0	E 65	U 10
13 Punching														U 10	U 0
14 Cleaning & Fettling															A 95
15 Dispatch															

Figure L.1: Relationship Matrix

Appendix M

Selection of the best facility alternative

The process of selecting the best facility alternative (Y_i) among those tested are as follows:

- For all the facility layout design selection attributes and every facility layout design alternative, thus for $\forall i, j$:
  - formulation of the decision matrix from the measured performance (x_{ij}) in $[Hours]$ of the facility layout design attribute simulation outputs for each layout alternative:

$$\begin{array}{c|cccc|} & C_1 & C_2 & C_3 & C_4 \\ Y_1 & 31.56 & 6.88 & 60.14 & 98.57 \\ Y_2 & 31.32 & 6.74 & 60.81 & 98.87 \\ Y_3 & 31.37 & 6.74 & 60.03 & 98.14 \\ Y_4 & 31.82 & 6.85 & 60.23 & 98.91 \\ Y_5 & 28.06 & 4.54 & 54.24 & 86.83 \\ Y_6 & 27.73 & 4.50 & 53.68 & 85.91 \\ Y_7 & 27.91 & 4.36 & 52.59 & 84.86 \end{array}$$

  - transformation of the performance ratings into a compatible unit through normalization:

$$x_{j,min} = min(x_{ij}) = 4.36[Hours]$$

$$N_{ij} = \frac{x_{j,min}}{x_{ij}}$$

$$\begin{array}{c|cccc|} & C_1 & C_2 & C_3 & C_4 \\ Y_1 & 7.23 & 1.58 & 13.78 & 22.59 \\ Y_2 & 7.18 & 1.54 & 13.93 & 22.65 \\ Y_3 & 7.19 & 1.55 & 13.75 & 22.49 \\ Y_4 & 7.29 & 1.57 & 13.80 & 22.66 \\ Y_5 & 6.43 & 1.04 & 12.43 & 19.90 \\ Y_6 & 6.35 & 1.03 & 12.30 & 19.68 \\ Y_7 & 6.39 & 1.00 & 12.05 & 19.44 \end{array}$$

- For every facility layout design selection attribute, thus for $\forall j$:
  - the calculated measures for every design selection attribute:

		Selection Attributes			
Measures	**Equation**	C_1	C_2	C_3	C_4
N_j	$\frac{1}{n}\sum_{i=1}^{n} N_{ij}$	6.87	1.33	13.15	21.34
Π_j	$\sum_{i=1}^{n}(N_{ij} - \bar{N}_j)^2$	1.19	0.49	4.25	14.76
Φ_j	$\Phi_j = \lvert 1 - \Pi_j \rvert$	0.19	0.51	3.25	13.76
Ψ_j	$\frac{\Phi_j}{\sum_{j=1}^{m}\Phi_j}$	0.01	0.03	0.18	0.78

- Selecting the best facility alternative:
  - the computed facility layout design selection index (Ω_i) for every facility alternative in ascending order:

		Ω_i $\sum_{j=1}^{m}(N_{ij} \times \Psi_j)$
Y_7	Product Layout with Suggested Fixed Process Sequence	17.42
Y_6	Process Layout with Suggested Fixed Process Sequence	17.65
Y_5	Current Layout with Suggested Fixed Process Sequence	17.84
Y_3	Product Layout with Current Process Sequence	20.12
Y_1	Current Layout with Current Process Sequence	20.20
Y_4	Combinational Layout with Current Process Sequence	20.27
Y_2	Process Layout with Current Process Sequence	20.28

  - the best facility alternative is the alternative with the smallest design selection index (Ω_i) as the attributes are non-beneficial:

    Y_7 Product Layout with the Suggest Fixed Process Sequence Facility Alternative

Appendix N

Recommended measurements for the improved fabrication facility layout

Workstation Name	**Number of Workstations**	**Measurement** $[m]$ **Workstation Length** (x)	**Measurement** $[m]$ **Workstation Width** (y)
Steel Cutting	1	14	9
Steel Bending	1	10	3
Pipe Cutting & Bending	1	10	9
Plate Cutting	1	23	9
Grinding & Reaming	1	10	9
Assembling			
Pre-Assembling	3	16	9
Normal Assembling	8	16	9
Large Assembling	1	30	9
Welding	7	10	9
Drilling	4	16	9
Punching	1	3	9
Cleaning & Fettling	4	18	9

Table N.1: Recommended Workstation Measurements

Storage Area Name	**Number of Storage Areas**	**Measurement** $[m]$ **Storage Area Length** (x)	**Measurement** $[m]$ **Storage Area Width** (y)
Steel Storage			
Normal/ Cut Steel	1	40	9
Large/ Uncut Steel	1	14	9
Plate Storage	2	16	9
Pipe Storage	1	9	9
Steel Cutting Storage	1	10	5
Plate Cut Pieces Storage	1	20	9
Weld Storage	1	20	9
	1	10	9
Drill Storage	1	30	9
	1	25	9
Punch Storage	1	9	9
Cleaning & Fettling Storage	3	20	9
Dispatch	2	18	9

Table N.2: Recommended Storage Area Measurements