Investigation and optimisation of an intelligent pre-paid water meter assembly line

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EXECUTIVE SUMMARY

The stakeholders and the background of the applicable companies related to the project will be touched on foremost and followed by the aim of the project as well as why the stakeholders were interested in bringing the project into existence. Included in the report is a full literature review on industrial engineering techniques and methods that could benefit the system after design and implementation. The procedures that were identified correspond to various portions of the organisation therefore the system will be broken down into these individual facets and a concept of how to streamline each process will be formulated. The succeeding step will be to combine these concepts to form a more efficient system.

The second phase of the project will attend to the actual design of the concepts created in the first phase and form them into working ideas ready for the implementation stage. The method that was the centre of the project that some of the other techniques (lean manufacturing, workforce multi-skilling and assembly line balancing) used indirectly was simulation modelling as it is a very flexible industrial engineering tool with many applications. The other techniques included workplace management, lean manufacturing with specific reference to constraints management and inventory management.

As with any project there are issues that restrict the possibilities and enforce certain boundaries concerning what the project will entail. These constraints, along with the resources available, ultimately sculpt the project into how it will address the problem. The concepts that were designed will need to be altered in order for them to fit into the system and for the concepts to collaborate towards an improved system.

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1. INTRODUCTION AND BACKGROUND

Teqnovo was responsible for the design, development and manufacturing of the first Teqnovo pre-paid water meter and were introduced into the market and implemented by 2004. Teqnovo's goal was to target the market outside South Africa (Nigeria, Tanzania Ghana, Zambia, Botswana, Namibia, India and Brazil) initially and provide water management systems for municipalities.

Owing to the capabilities of these water meters, it was realised that the municipalities in South Africa could also benefit so Lesira-Teq was formed by Teqnovo for exactly this reason (in the beginning of 2006). The sister company remains a separate entity from Teqnovo and is concerned with providing the support and sales functions for their South African clientele.

Teqnovo underwent a restructuring and Efteq was born in January 2010. Efteq established itself in the development of the water demand technology industry in South Africa by using the knowledge from Teqnovo and assembling the unique range of water meters. This is a process that comprises of a mechanical valve system being married to an electronic mini-computer and these parts communicate with each other and measure the amount of water used. This technology has several applications and configurations to meet the consumers' needs to regulate the water usage. Efteq caters for a number of additional services to end-users such as post-sales maintenance and accounts management with the idea of minimising the cost of implementing a water management system whilst keeping water consumption savings a priority.

Esteq is a computer software consulting company that buys engineering software and re-sells them with add-ons and client specific extras to accommodate the clients' requirements. Their business scope also includes consultation, post sale support of the product and training of the clients with respect to the software and new system implementations.

Figure 1: The pre-paid water meter range

2. PROJECT AIM

The focus of the project will be to identify constraints (including resource allocation and workplace management) within the assembly process and apply the relevant techniques to streamline the assembly line.

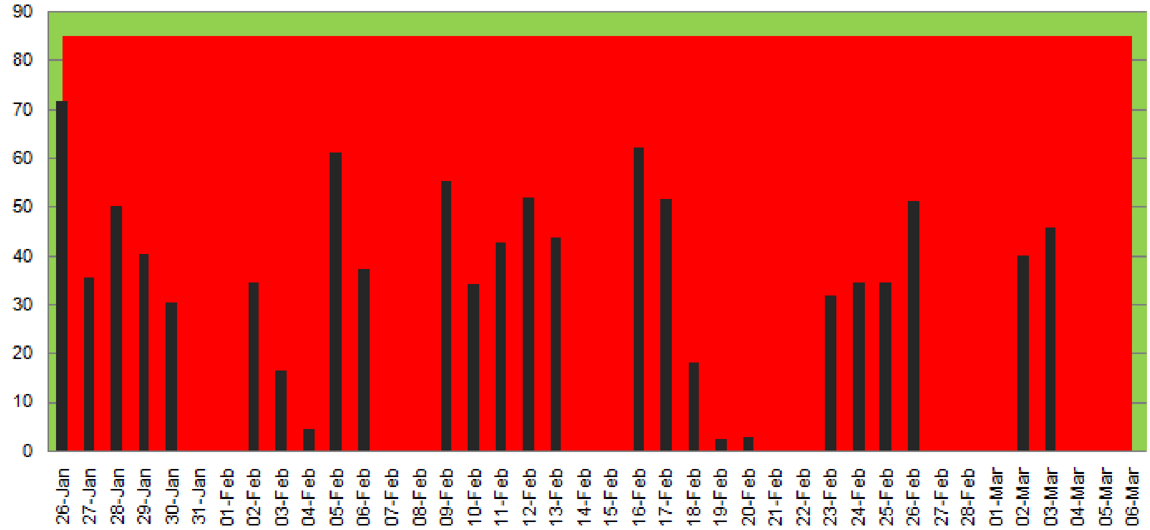
3. PROBLEM RATIONALE

The project was initiated by Dr. Pierre Fourie, the Managing Director of Efteq as there is significant improvement opportunities on the assembly line and that the concern that sections of the system were not at their optimum production capacity. (Figure 2)

The products that are assembled in the factory are of a high unit price (some over 300 rand per component) and therefore having large excess stock would give rise to capital expense implications but at the same time if there were too few components available then production would stop altogether. This would bring about a backlog of supply, customers would have to wait and customers could even be lost (loss of goodwill). This presented an opportunity to introduce a form of inventory management.

The assembly process is purely manual and each of the labourers have single tasks to complete before the product is shifted downstream. Due to the fact that it is a manual process, it is subject to a large amount of variance and resource allocation is an issue with respect to allocating resources based on the current production schedule. The idea is that there would be fewer workers required if the production need dropped from 500 units per day to 250 units per day. The right amount of workers would guarantee the production demand is satisfied and Efteq should never be short on workers and more importantly not have idle resources which add to variable costs. A simulation model would allow for a graphical illustration of what would happen given a specified amount of workers and units that needed to be produced.

Every item or component that forms part of a water meter needs to be of certain quality before it is allowed to be assembled, thus each unit is inspected extensively as it continues down the process and from this quality is assured. The implication is that the right amount of quality measures will need to be in place for an acceptable product to be produced. The question is; what and where along the line should the quality checks be inserted?



	26-Jan	27-Jan	28-Jan	29-Jan	30-Jan	02-Feb	03-Feb	04-Feb	05-Feb	06-Feb	09-Feb	10-Feb	11-Feb	12-Feb	13-Feb	16-Feb	17-Feb	18-Feb	19-Feb	20-Feb	23-Feb	24-Feb	25-Feb	26-Feb	27-Feb	02-Mar	03-Mar	04-Mar	05-Mar	06-Mar
% Taget	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85
% Output	71	35	50	40	30	34	16	4	61	37	55	34	43	52	44	62	51	18	2	3	32	34	34	51	0	40	46			

Figure 2: Difference in throughput target and output as a percentage (adapted from the annual factory review '09)

4. PROJECT SCOPE

Optimising multiple aspects identified in the assembly line and implementing a way for them to synergise with one another will allow maximum benefit to be derived from the project. The following ideas were generated by the student and the stakeholders at Efteq in the initial introductory meeting:

- The process is manual labour intensive and thus is subject to a large degree of variance and hence they do not know how to allocate the right amount of labour according to the production schedule. Simulation could be used in accordance with time studies to construct a generic model that will use inputs from the production schedule to determine the quantity of workforce needed to achieve the required throughput targets. (Figure 2)
- The right degree of quality assurance and control will also be addressed as calibration, verification and testing is performed on each unit which is time consuming. The right amount of quality control in the right place will eliminate redundant quality checks and ultimately increase throughput. Thus the effect that these quality measures have on the flow of the product through the system will be analysed with simulation.
- Combinations of multi-skilling for the work force will be regarded in the idea that giving one labourer multiple tasks could increase production levels as well as introduce a new level of job satisfaction.
- Refine the systems responsiveness as a key performance indicator which would in turn influence the amount of safety stock kept in-store due to the fact that inventory control is a cause for concern. A substantial amount of capital is caught up in stock form; work in process and finished goods. (It is evident how much capital is caught up in material as indicated by the highlighted totals in Table 1.)
- The layout and alternative concepts of how the workers are arranged will be addressed using new material flow friendly designs.

Coupling all these solutions together will potentially streamline the process and save costs as well as time for Efteq.

Table 1: Stock status after annual factory review (adapted from the annual factory review '09)

Material	Value (R)	Total
Raw material	4,331,906.42	
Work In Progress (WIP)	1,203,862.30	
Total		**5,535,768.72**
SUB and Finished Goods		
Sub assembly	1,874,035.25	
Finished goods	1,319,814.63	
Total		**3,193,849.87**
Accumulated Total		**8,729,618.59**

5. LITERATURE REVIEW

5.1. Lean Manufacturing and Workplace Management

When combined, *Muda, muri and mura* form a catchy Japanese phrase that is commonly associated with manufacturing methods or even a method to carry out simple tasks. These words (the three M's) are directly related to the origins of lean manufacturing which have the meanings; wasteful, irregular and unnatural activities or processes that plainly add to manufacturing costs. Eliminating these three M based costs forms the basis of what lean manufacturing entails, as said by (Mente, 2004). It is interesting to note that the terms 'lean production' or 'lean manufacturing' were only first introduced in 1990 in a historical book called *The Machine That Changed the World*. It was added that this approach is not just a practice, but a culture where the parties of the organisation focus on continuous improvement (Womack.J, 1996). The Japanese have been using this way of life for years and only later combined it with production systems. This revolution was instigated by the Toyota production systems when they sought to find a balance between being lean and operating a mass production system. (Shahram Taj, 2006)

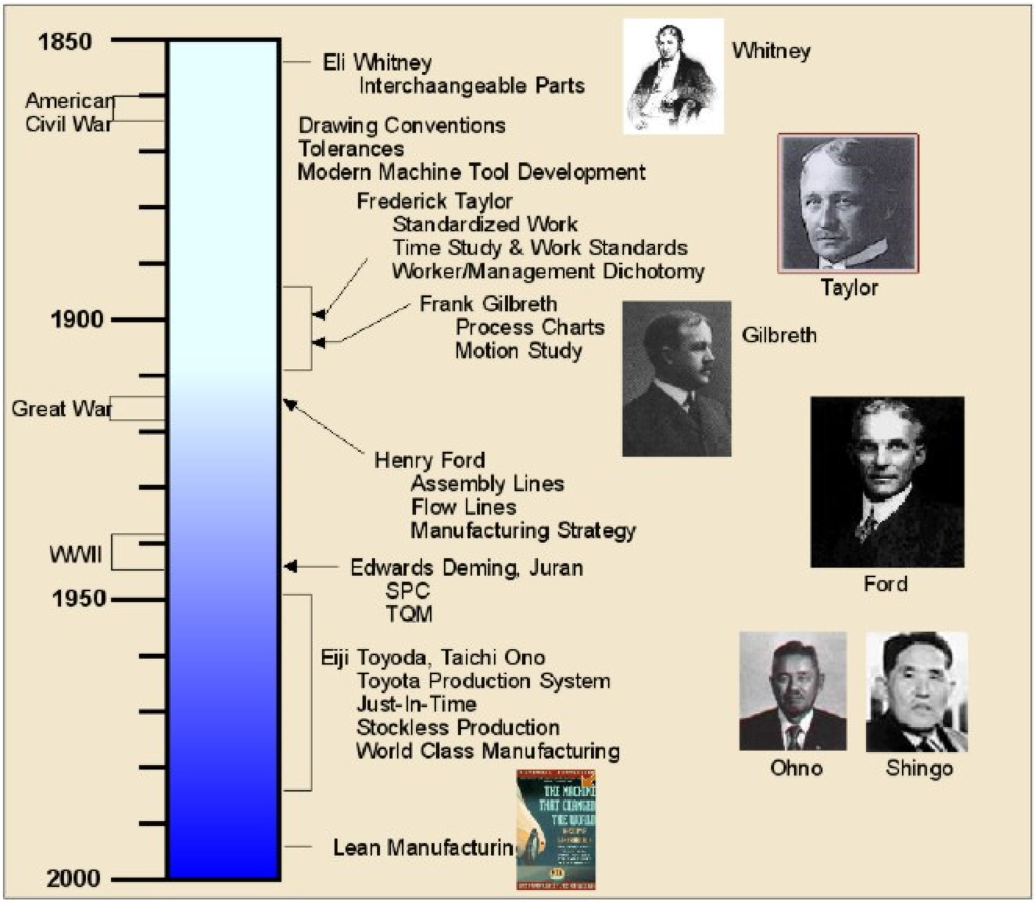


Figure 3: Lean manufacturing history

These principles have permitted firms in the service and manufacturing areas to significantly improve their competitiveness for many years, as seen in figure 4, by simultaneously developing their productivity, customer service and quality. These operational functions are some of the key utilities that influence the success of a business and grant it the necessary competitive edge to stay in the running in an ever growing competitive environment. (J.Riezebos, 2009)

The basic lean approach is concerned with sinking waste in the value stream and according to (Shahram Taj, 2006) there are eight waste categories, namely:

1. Motion: human movement that does not add value.
2. Waiting: material, information, people or equipment not ready (causing idle time).
3. Correction: work containing defects or errors and need to undergo a necessary step or rework.
4. Over-processing: effort that adds no value. I.e. unnecessarily overshooting customers' needs.
5. Over-production: producing more than what is needed. Results in too much stock on hand.
6. Transportation: non value added product movement.
7. Inventory: materials or products waiting for orders or to become 'wanted/needed'.
8. Knowledge: people performing the tasks with sub-standard levels of confidence to perform the task at hand.

There is no general way to implement a lean system that will apply to all businesses, it is an instance specific technique and the basics need to be customised and altered to suit the company. As shown in figure 3, with the Boeing lean manufacturing setup, only ideas from other organisations can be taken into consideration when addressing the lean manufacturing components at Efteq. It is astounding to know that even the top lean manufacturers waste approximately thirty percent. Although thirty percent is still a large portion, it is a significant improvement in comparison to most other companies who waste between seventy and ninety percent of their resources. Thus by addressing the strategic matters of the business when planning lean manufacturing plants is an essential perspective that should be considered first and foremost. (Ghorashyzadeh, 2003)

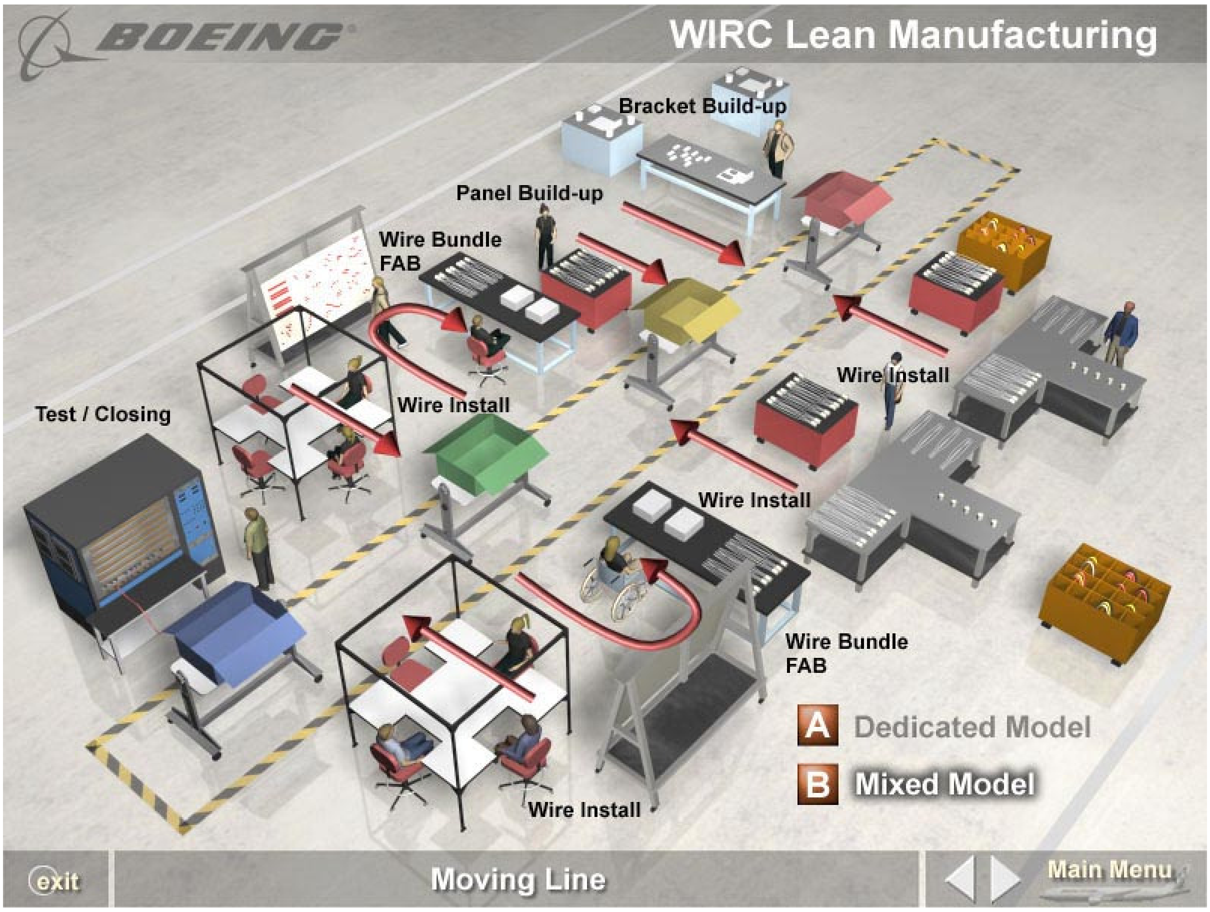


Figure 4: Lean manufacturing setup at Boeing

Constraint management goes hand in hand with lean manufacturing in that it aims at improving productivity as a whole by solving the problem of bottleneck resources. Iterating this process will speed up the system and new bottlenecks will form as a result of the previous ones falling away. Iterations of this procedure will continue to improve the throughput even though there will always be a process drum (the task which determines the beat/ rate of the system). The underlying goal is to produce the same amount of finished product with fewer resources used or alternatively produce more with the use of the same amount of resources. (Shahram Taj, 2006)

(Goldratt, 1995) Proclaimed, that the first task, when removing constraints, is to set a goal which is to build the maximum amount of acceptable products at minimum cost. This requires six stages (also known as the theory of constraints):

1. Define the system.
2. Identify the constraint in the system.
3. Figure out how to exploit the constraint.
4. Subordinate all else to the decision in 3.
5. Bring the system's constraint to the front.

6. If a constraint is broken in Step 5, go back to Step 2.

Following these steps will prevent large scale blockages (excess inventory waiting for the bottleneck process to free up) and starvations (processes waiting after the bottleneck) from occurring.

In order to recognize a bottleneck, the overall assembly must be broken down into the separate processes in order to identify which process is the major constraint (has the lowest jobs per hour) and ultimately affects the lines throughput, says (Aidenbaum, 2003). After finding the process that constrains the system the most, the next step is to analyse this area as a process itself, break it up into its procedures and then identify, from this, a deeper reason as to why this an area of concern can be discovered and subsequently a solution to the problem will be formulated.

Necessary measures can be taken through the necessary steps to implement the improvements and subsequently establish a guideline for a better practice which should be documented/recorded. It is essential that in doing so, improving productivity should not negatively impact quality but rather increase it or remain constant.

The constraint management technique is a never ending cycle with the ultimate goal of pursuing continuous improvements for the system. Even before the implementation of a fully or even partially lean system, factories can benefit from a continuous improvements program, (Mortimer.AL, 2008) . In such a case, any form of lean implementation will not necessarily deliver performance enhancements but will uncover how much potential for lean improvements are currently in the business from a cost and waste reduction perspective. This implies that even if the system seems to be running smoothly and improvements have perpetually been sought out, lean methods should discover something of value to add to the business.

The flexibility of the system will pose a problem when lean or any form of measures for improvements are initialised as the changes could send the system into shock (the difference between theory and practice manifesting itself). This is especially difficult if out of date manufacturing methods are still employed as they have a lower degree of flexibility, but the idea is to customise the system into adopting the additions to the system. If this can be accomplished the system will experience an increase in responsiveness and efficiency which are two of the many aims of lean manufacturing.

Gembi Kanri, also known as workplace management is a type of management strategy used to expose specific issues in the operator-and-process interaction area and to focus on efforts aimed at solving these problems. (A.L.Mortimer, 2006) It was noted that getting the operators more involved with the output and performance of their area of the process had the effect of bringing them closer to the process as a whole and was an element in increasing the success of the operator cell. If the operators are convinced that they are an important cog in the big machine, for example extending their responsibilities and making them observe the quality of the output and recording it. This will have the result of a closer knit workforce being formed. (Mortimer.AL, 2008) This supports the ideals of lean manufacturing in that the operators become aware of what and why things are done and are not just pawns in the system. This form of management is often not recognised by senior management and the consequence overlooking of this technique could result in a healthy system being run with less consideration and attention from the operators than what is essential.

In addition to the Kaizen outlook, Ishikawa for the purpose of defect prevention or process improvement is another management tool that could be introduced for process analysis reasons. The worker would be able to identify the problem or the opportunity and give reasons for why the problem has occurred. These diagrams will take a look at the people, methods, machines, material and environment facets of the problem and a brainstorming session thereafter to address the problem would be used to generate solutions.

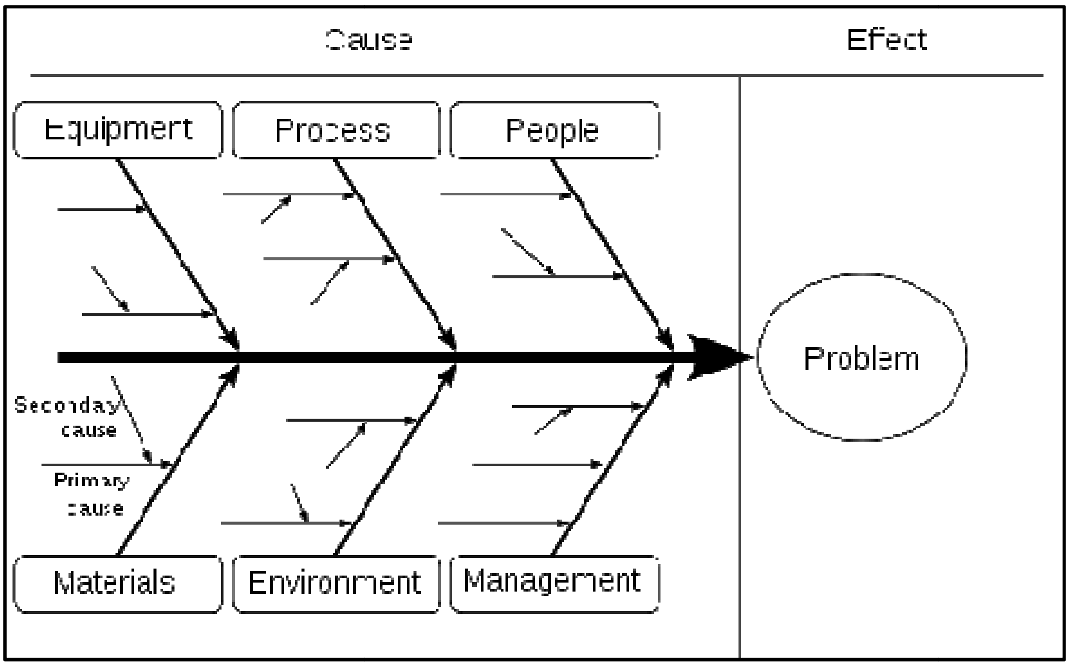


Figure 5: Ishikawa diagram for process analysis

5.2. Simulation Modelling

A model is a representation or concept of anything, whether it be a system or a single functioning entity and simulation is the act of experimenting with the model in order to ascertain how the system will react to outside influences or inputs specified by the user. Depending on the focus of the model, this information would provide the experimenter with insight into numerous significant business parameters, from performance to material flow to the success of a training program. (Balci, 2001)

It is clear from the above statements that simulation can prove beneficial to most systems where variance is an issue and when the right parameters are setup in a generic model for the system any change in the inputs will accurately show how the systems reaction will yield a positive or negative result. In addition to this, Simulation modelling could be the representative tool in a continuous improvement plan as potential advantageous alterations to the system could be cheaply tested before implementation on a continuous basis.

The design of production systems has always been an important problem in industrial engineering (Dolgui, 2001) as a result of the rapid progress of manufacturing technologies. It is important that these designs be constantly altered to allow for the emergence of new technologies that would allow the business to remain competitive in the respective industry, the need for new methods and CAD tools (for insight and furthered knowledge) becomes apparent as this would prove to be the best way to trial run new system implementations. (Rekiek B. D., 2002)

This presents the opportunity for simulation modelling software to be utilised as a CAD tool to design the optimal production or assembly system and monitor how it performs without the hefty capital brunt of the actual implementation. The process would be one of trial and error where different concepts are built using the software and are compared using a common set of parameters, and from this a winning concept is chosen. This is the way forward for concept prototyping as model building and simulation are becoming simpler and quicker through the implementation and progressions in software and hardware stated (Zeigler, 2000).

As it is assured in “The Handbook of Simulation” by (Banks, The Handbook of Simulation, 1998), that simulation is consistently one of the major three techniques used by industrial engineers, management scientists and operations researchers and is sometimes even referred to as the last resort methodology. It has been considered as an indispensible problem-solving practice and used throughout the globe in the quest for solutions to many real-world problems.

With any methodology there are advantages and disadvantages, some of the disadvantages of simulation include:

- Training is required for model building – experience is only built over time.
    - Solution: generic models are available and require only plug and play.
- Can be time consuming and costly – if these are cut to save time and money, the model might not represent the system accurately.
    - Solution: with new hardware and software capabilities, the time and therefore cost can be significantly reduced.
- Simulation used incorrectly – analytical models would be favoured yet simulation is used.
    - Solution: limit the complexity of the model or simply use an analytical model.
- Results may be tricky to understand – complex as the result may be related to either randomness or system interrelationships.
    - Solution: in depth analysis methods will be able to discriminate between the two. (Banks, The Handbook of Simulation, 1998)

According to (Banks, The Handbook of Simulation, 1998) conceptualising a model involves insight into the process, engineering judgement and obviously model building tools. The modeller must know how the system functions and how it interacts with other sub-systems and have knowledge of, with enough certainty, the flexibility of the system and how it would react to alterations. With this knowledge, the modeller will be able to affix the right assumptions (present in every model) and realistically imitate the important characteristics of the process and meet the modelling objectives.

There are important steps to follow when performing a simulation study, these will act as a guide line for the modeller and after the analysis of three sources have been found to be a generic method when attacking a simulation study. This particular one is an extract from Banks et al. (1996):

Problem formulation: each study of a simulation starts off with a problem. The problem is defined in a statement that accurately describes and emphasises the main points of what the study is to entail making sure that the parties involved (analysts and clients) will fully understand it. It is essential that the client agrees with the statement and the subsequent step would be for the analyst to list a set of assumptions that will help with the modelling process at a later stage taking into account that the client has signed off on the list. Although this is a vital part of the study it is often found that the problem will be re-formulated as the study develops.

Setting the project plan and objectives: this is the step where a proposal is made to specify what questions will be answered by the simulation and the project plan should include what exactly will be simulated, the possible alternate situations that will be discussed. The project plan should also detail a timeline or Gantt chart for the deliverables, the personnel and equipment usage, cost of the study, stages in the investigation and output at each stage should all be specified.

Model conceptualisation: the actual system in the real world is abstracted sing the data that has been collected and align them with the objectives that were set earlier, the model is the translated into a working model and then verified and validated at later stage.

(Robinson, 1994) Implies that an effective model is usually the simplest one as these types of models have advantages over complex ones. The advantages include rapid development, flexibility, the outputs are easier to interpret (easily understood) and faster running time, and these advantages are lost as the complexity of the model increases.

This is supported by (Pidd, 1999) and the six principles of modelling which are:

1. Model simple but think intricate.
2. Be prudent by building on a small model.
3. Split up the system and model separately to prevent mega models.
4. Use metaphors and analogies.
5. Don’t bombard the model with data.
6. Developing the model may seem like muddling through.

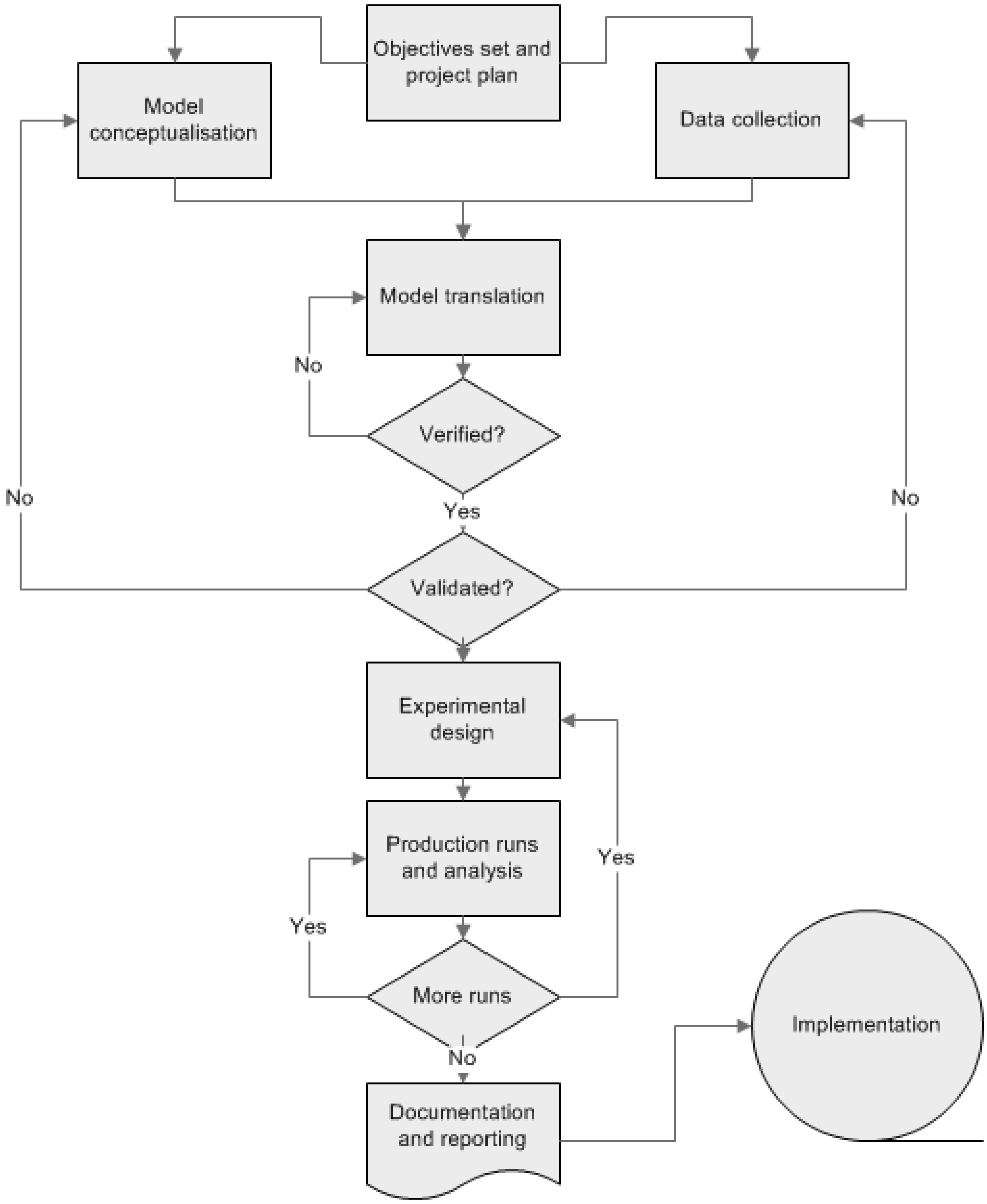


Figure 6: The simulation process after problem statement

The operational model is the physical model that should realistically "behave" the same way as the real world situation. This model is developed from the conceptual model which is hard coded into the operational model and by this the concept is translated into a working virtual system. Lastly there are two major procedures left for ensuring that the model is a realistic representation of reality, these are verification and validation and are executed as follows:

Verification: Determination if the translation from the conceptual model to the computer model was successful and whether the operational model is an accurate virtual representation of the conceptual model.

Validation: Validation is the process of determining if the conceptual model can be directly substituted for the real system to function as a trial model.

These two processes need careful attention as they form a valuable tool when the modeller finds discrepancies between the conceptual model, the operational model and the real world system. The procedure is an iterative one and after each time this procedure is performed the modeller should start at the beginning again to ensure that the changes that were made brought the conceptual model closer to reality and thus striving for a perfect model.

The operational model will prove to be redundant if the model is not designed to measure the proper outputs, this has the affect of a model calculating information that is not necessary. The simulation analysis begins by choosing what the modeller wants to deduct from the model and setting up the model in this way to revolve round the performance measures of choice. These performance measures can be anything from a counter, to expressions such as means and variances, queue length, waiting time to name a few. (Banks, 1998)

These steps of model building are summed up in three broad titles in (Fishwick, 1994) as model design, model execution and execution analysis as seen in the following figure including their sub sections:

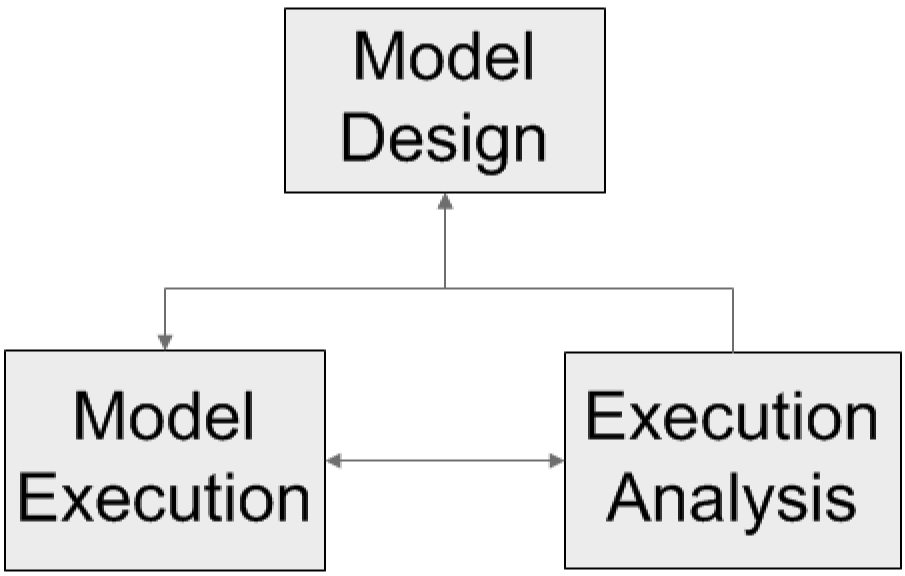


Figure 7: Three main modelling steps

From the above insights it is clear of the benefits that simulation can impose on a system but at the same time it is illustrated how fragile and sensitive the model development phases can be. Thus the modeller needs both training and knowledge with the simulation itself and with simulation related subjects in order to accomplish a successful simulation study.

5.3. Inventory Management Methods

There are numerous ideals that all inventory managers pursue in order to better their section of the business and these include:

- Profit maximising
- Maximise rate of return on stock investment
- Cost minimisation
- Maximising the chance of survival of the business
- Guarantee the operations flexibility
- Establishing a feasible inventory management solution

There is a list of constraints that hinder the managers from achieving these said goals. They include:

- Supplier constraints – minimum and maximum order quantities, lack of supply, extended lead times
- Marketing constraints – the minimum customer service level that needs to be complied with
- Internal constraints – storage and budget restrictions

Choosing the correct inventory management strategy and fitting it to the appropriate type of business will allow these goals to be aligned to the business strategy, the proper tradeoffs will be selected and the business will attain an efficient inventory management policy. The issue is discovering what strategy will be the best fit for the business. (Silver E. , 1981)

An ordering system that follows the push type production scheme is described as the case where production orders are issued based on either forecasted demands or inventory information (gathered from the production process) or both. It is vital for the business to have an efficient yet simple method of handling production planning and inventory management which would subsequently manage the intensity in the variation in both inventory levels and production ordering. This would have the effect of turning a purely stochastic process into a partial or fully deterministic process and bring it under a new degree of control. (Matsuura, 1991)

Material requirements planning (MRP) is the most well known and popular example of the push type production and ordering systems, and is used globally for real-life manufacturing planning and ordering. (Orlicky, 1975)

In the push type ordering technique there are two different netting systems, the first is the full netting system where the order quantity is derived from the accumulated forecast demand using the total lead times until the final production stage. The second is the single netting system where the ordered quantity is based on the individual forecasts during the lead time of each production stage. The problem is to determine which netting system will work for the unique production systems or if would prove more beneficial to use a combination of the two. In order to do this the two methods are run concurrently with the two performance measures; production ordering and inventory level variations, and then making quantitative evaluations between the two. (Matsuura, 1991)

Production ordering variations and inventory level variations are the key performance measures, this is due to the fact that a poor netting system will consequently lead to bigger variations in the economic ordering quantity which would allow for unnecessary increased production and would further translate into elevated inventory costs. (Matsuura, 1991)

A classic planning system begins with a demand forecast of each individual product over a few time periods, from this a production plan (master schedule) can be constructed to meet the demand. Using the lead times for the processes and back-tracking accordingly would produce a forecasted requirements plan detailing what components will be needed and when and this information would be combined with the production plan. This process is iterated for every part needed in the consecutive stages in the bill of materials (BOM).

The downfall of this method is that it relies on the assumption that the demand forecast is accurate and is not likely to change, thus your production schedule is dependent on how well your data is formulated (the forecast is the key input for the model). Apart from this there is also a snag concerning the actual production process where it is assumed that all lead times (usually known but subject to variance) are deterministic and therefore predictable. Both occurrences will generate deviations from the original plan and in order to minimise the effect that this will have on the system, it would be helpful to review the plan on a regular basis and adjust it accordingly so that there will be no surprises when it comes to delivery date. (Graves, 1998)

The measures of interest that the model will assist with, fall under three categories namely; the smoothness of the production outputs, the safety stock and the stability of the production plan. The aim for all of these outputs is to decrease the amount of variance present in each and in doing so gain a form of control over the process. Safety stock will concentrate on how much inventory to carry in order to satisfy demand on time yet keep stock at a minimum to save additional unnecessary carrying costs.

The table below details costs and other important factors that need to be considered when regarding a new type of inventory management solution. (Silver E. P., 1998)

Service Requirements • Customer expectations • Competitive practices • Customer promise time required • Order completeness required • Ability to influence and control customers • Special requirements for large customers	*Customer Ordering Characteristics* • Order timing • Order size • Advanced information for large orders • Extent of open or standing orders • Delay in order processing
Demand Patterns • Variability • Seasonality • Extent of deals and promotions • Ability to forecast • Any dependent demand? • Substitution?	*Supply Situation* • Lead times • Reliability • Flexibility • Ability to expedite • Minimum orders • Discounts (volume, freight) • Availability • Production versus non-production
Cost Factors • Stockout (pipeline versus customer) • Carrying costs • Expediting • Write-offs • Space • Spoilage, etc.	*Nature of the Product* • Consumable • Perishable • Recoverable/repairable
	Other Issues • A-B-C pattern • Timing and quality of information • Number of stocking locations • Who bears the cost of inventory?

Figure 8: Important economic factors affecting inventory management policies

5.4. Parallel Sequencing and Assembly Line Issues

Concurrent engineering has the objective of reducing development or production time for the product as it progresses through the system, this is due to a multitude of factors but mostly owed to running two or more tasks, dependant or independent of one another, simultaneously. Process design management is a complex subject as coupling the wrong tasks together could extend the completion time of the system, hence it is imperative that the constraints as well as the process is thoroughly understood. In a concurrent engineered system the feedback procedure is responsible for improving the quality of the design, the problem is that this procedure is repeated and thus uses up precious engineering time. In order to implement concurrent engineering methods and to counter-act this effect, frameworks are developed to evaluate when which tasks should be performed (the manufacturing or assembly process is designed in conjunction with the product itself.

The initial step is to understand, from the engineers and managers point of view, the nature of the tasks that need to be performed to complete a single product or batch of products. Design process models are utilised to gain the understanding needed, these models are in the form of design structure matrices and will aid in realising the key tests and tradeoffs in the organisation of the design system. From these results different approaches will be appropriated and compared to one another to identify the most suitable design strategy for the system.

There are three possible ways in which two tasks can be related, either dependant, independent or interdependent. The dependant tasks would usually be in series as the second process in sequence requires the output from the first process, the independent tasks would be placed in parallel as they do not rely on each other and lastly interdependent tasks are coupled together and the interactions between the two tasks specified as seen in the figure below.

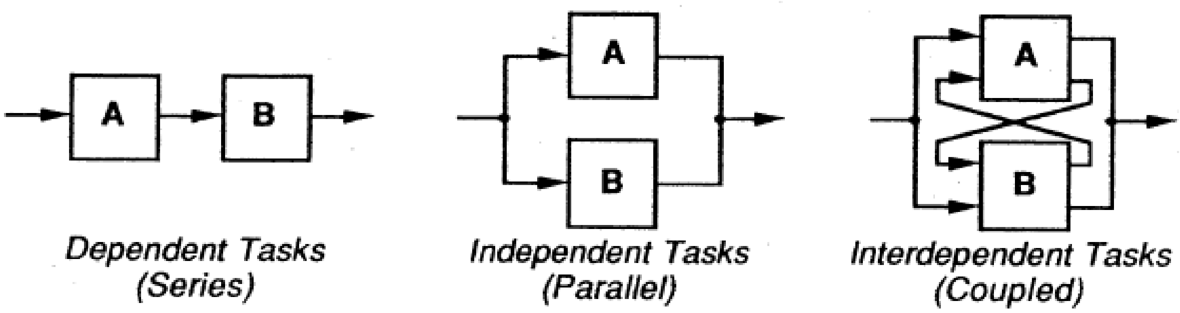


Figure 9: Three possible sequences for two separate tasks

It is simple to co-ordinate the dependant (series) and independent (parallel) and it is obvious that the independent tasks can be completed at a much faster rate, provided there are no resource restrictions. The interdependent tasks are considerably more difficult to organise as they need more design time and a meticulously configured information transfer system. (Eppinger S. , 1991)

(Steward, 1981) Has developed a design structure system which provides for coupling any two tasks together. The tasks are given an assigned letter and are listed alphabetically in both row and column sequence. The marks in the row indicate which tasks (in columns) should be completed before the row task can be completed, this process gives an idea of the predecessor and successor setup. The successive step is to sequence the tasks so that the matrix becomes almost purely lower triangular, if this is accomplished then each task can start with all the information or inputs it needs and there are no longer coupling issues in the system. due to most systems being significantly more complex than the theoretical ideal case, the matrix usually becomes a matrix in block-angular shape as shown in (b) of the figure below.

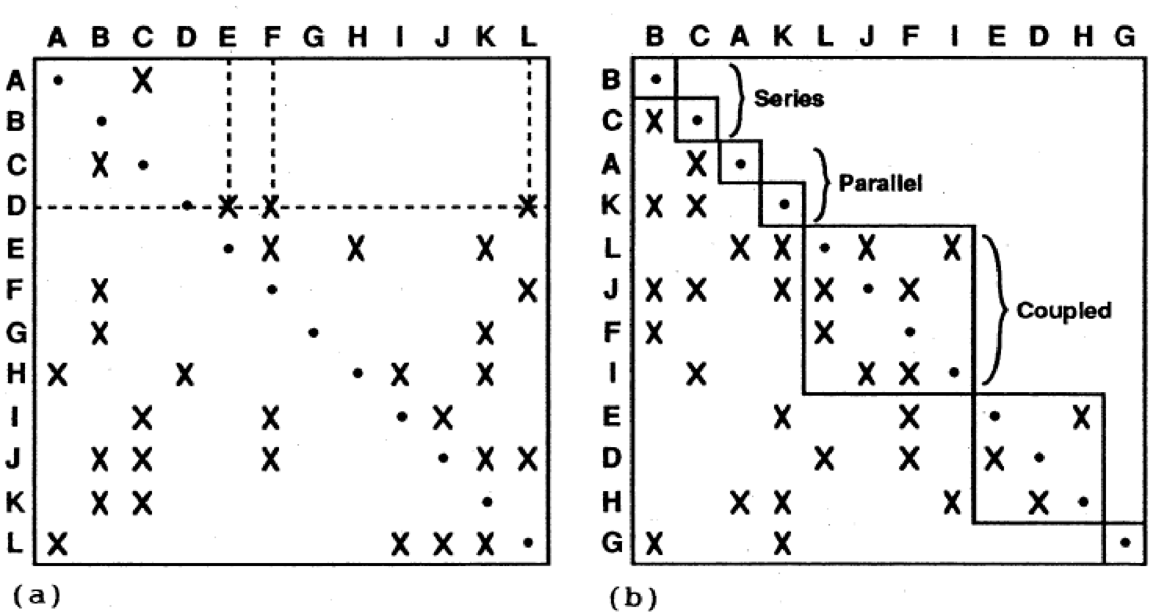


Figure 10: Stewards design structure matrix, (a) is the original matrix and (b) is the partitioned matrix

The step of going from matrix (a) to matrix (b) is by checking for dependency, putting them in series, independency is placed in parallel and the ‘blocks’ are the coupled and the most complex part of the design challenge. The design structure can be used as a modelling tool and the design team needs to analyse how well the sequence fits in with the technical structure of the design tasks as this has the potential to recognize prospective improvements to the design process.

A variation of the Steward Design structure matrix is used in (Eppinger S. W., 1990) to represent the sequence and technical relationships that exist between the design tasks that need to be completed. These ultimately define the technical structure of the design project. The variation imposed on the original Steward matrix is to use a numerical number to illustrate the importance of each task dependency which will hep to decide on the task sequencing later in the process.

	B	C	A	K	L	J	F	I	H	D	E	G
B	1.5											
C	.54	2.8										
A		.94	4.2									
K	.40	.59		2.0								
L			.27	.95	1.8	.91		.20				
J	.45	.87		.09	.94	3.4	.59					
F	.38				.51		2.1					
I		.81				.22	.47	1.4				
H				.16			.28		8.5		.62	
D					.39		.92		.45	3.3		
E			.90	.05				.80		.33	1.9	
G	.96			.88								6.7

Figure 11: The numerical design structure matrix (an adaption of the Steward design structure matrix)

The strategies used by (Eppinger S. W., 1990) for enhancing the design process are parallelisation, artificial decoupling and increased coupling. These strategies have the following benefits:

Parallelisation – placing tasks that are independent of one another adjacent to each other rather than in series will ensue a faster throughput time equal to the largest led time between the two tasks instead of the sum of the two.

Artificial decoupling – in a group of loosely coupled tasks, removing a dependency allows the group to be divided up into smaller tighter groups. In order to remove a dependency an extra task would have to be performed earlier to satisfy this dependency before it reached that point in the sequence.

Increased coupling – this forms the basis of concurrent engineering and will indefinitely reduce production time as it allows tasks to be executed simultaneously. Although it is recognised as a method for improvement, it has been known to impede on the design process due to the amount of information transfer required.

5.5. Facilities Planning and Layout Design

According to (Tompkins, 2010) facilities planning used to be a science but in today's competitive market it has become a strategy that ranges from cook-book style methodologies and check lists all the way to mathematical models. No matter what kind of facility you are analysing there is no generic model or memo to follow to accomplish the objectives of facilities planning. Although this is true, the only thing that remains constant are the aims of this technique, these include maximising space utilisation, designing the layout to increase the product flow, exploiting the opportunities for cost reduction and productivity improvement and using the fact that it is a long term commitment to plan for the future.

A facilities planning study is an integral part of process design as the space available needs to accommodate all the business functions and in such a way that it maximises the ease of process execution. The production or assembly floor needs to be organised to promote performance characteristics such as material flow and information flow, a good reason to seek supplementary methods for doing so as every plant or production area is different and therefore open to creativity.

5.6. Assembly Line Balancing

Assembly systems are the most popular forms of mass production systems as it allows relatively complicated components to be manufactured by a team with limited training because of how repetitive each job is. The ultimate endeavour for an assembly system designer is to make the process as efficient as possible by playing with the ratio of costs to throughput rate. This is the exact reason why assembly line design is of such industrial importance, says (Rekiek B. D., 2002).

The bin packing approach is used for an assembly line that produces only one product, assumes the task durations are fixed and assumes that the operations can be completed in any order. The basic concept is to fit these operations (objects) into equal sized bins (containers) and see how many workstations are needed. Now this isn't necessarily the most accurate way to design an assembly line but adding acyclic constraints to the system transforms it into a typical simple assembly line balancing problem (SALBP).

There are two types of SALBP as stated by (Scholl, 1999), the first is where tasks are assigned to stations with the focus of minimising the amount of stations for a known production rate. The second form is where the aim is to maximise production rate and decreasing the accumulation of idle times for a given number of stations therefore depending on the constraints of the system one would be investigating and from here, one of these assembly line balancing methods will be used.

Different line configurations have their advantages and disadvantages and consequently only perform optimally in certain situations, the process of selecting a line configuration can be a trial and error test but will most likely be based on previous experiences. A number of line configurations are listed below as well as where they are generally used:

Serial line:

A line of single stations along a conveyor with a sub-assembly occurring at each station.

U-Line:

The introduction of the JIT (just-in-time) system brought into light the advantages that the U shaped assembly line could have. These advantages include multi skilling among workers which increases job satisfaction and subsequently improves the overall products quality and system flexibility.

Parallel stations:

In a system with high throughput volumes, some task times surpass the cycle time thus introducing another station to carry out the same task which decreases the average time for the bottleneck task (proportional to how many workers are introduced). (McMullen, 1998)

Parallel lines:

In the same way as electrical components can still function if there is a short circuit in a parallel circuit, this line configuration reduces the sensitivity of a station failure and even allows for an increase in cycle times due to the average principle.

Work centres:

When the system is required to produce complex products it is usually best to divide the system into sub-assemblies, known as work centres, as these are easier to control. The material flow is then routed through the centres until the finished product is completed. (Rekiek B. D., 1999)

There are many others such as robotic assembly lines and parallel tasks (blocks) but will not form part of this review.

Academic algorithms are not used in the industry because of the lack of data capturing capabilities and oversimplifications. Even though academic algorithms are not applicable in the real-world, proficient methods in assembly line planning and the use of resource planning should have the capacity to handle the users requirements and tradeoff areas whilst remaining a speedy method of comparing alternatives.

The literature compiled in this paper was done in the pursuit of engineering or more specifically industrial engineering techniques that could be applied to a real-world assembly line problem. The aspiration of this project is to streamline the processes at Efteq in more than one facet of the organisation. The approach that will be taken is to break up the processes, optimise each and then combine them with the hope that it will result in the entire system benefitting.

6. PROJECT ENVIRONMENT AND DATA ANALYSIS

The information and data was collected during a number of factory visits and meetings and the project requirements were established. Efteq was able to reciprocate most of the requests, however there is some information that cannot be released due to the pending intellectual property statuses and thus will not be disclosed in the project.

In different aspects of the project, methodologies require certain information from the system in order for the technique to analyse and optimise that part of the organisation effectively. Below is a table of what specific information the methodologies require and in what form it was made available by Efteq:

Table 2: Acquired data for engineering methodologies

Method	Data required	What data has been procured
Resource utilisation	Resource description and operator task interaction	Time studies and operator specifics
Work flow simulation	Layout and network diagram of task dependencies	The layout plan and material flow between assemblies and sub-assemblies (incl. Dependencies)
Lean manufacturing	Process description, system constraints, lean methods and guidelines	Detailed process description and system flexibility
Layout design and optimisation	Current layout, layout alternatives and guidelines	Extensive current layout, techniques of implementation and design ideas.
Assembly line balancing	Task relationships and task times	Time studies for each task and how the material flows between them
Inventory management	Inventory management design strategy, tools to aid in identifying areas of improvement	Current inventory management system and guidelines in management expansion

All the necessary research and data capturing has been done in order to initiate each one of the above mentioned techniques and to begin formulating procedures and identifying areas of potential improvements specific to this system. The next challenge would be to implement these improvements and ensure that they can co-exist and still add additional value to the output of the system and will be discussed in conceptual designs.

Note that all the information needed for the techniques specified would exceed the limitation of this paper so a few of the more major data requirements such as the detailed explanation of the task sequence and task times can be found in the Appendices.

7. TECHNIQUE REVIEW

From these techniques, numerous conceptual designs were formulated specific to the system at hand which allowed the student to prioritise these ideas according to which would have the largest anticipated benefit for the business.

Simulation was the first method that was reviewed and it was found that this technique holds the most benefit for the system, not only because it would give useful insight into the process by identifying shortcomings in the system, but it will execute this task at a very cost effective level. In addition it will also be used as a trial tool where virtual alterations were made to the system and the model analysed thereafter. Alterations will deal with moving around processes, implementing personnel multi-skilling by unifying tasks and adjusting the process sequencing.

Lean manufacturing is known not only as a technique but as a culture and a way of life for a group or organisation to focus on continuous improvement. Lean methods such as waste reduction and management will be the focal point techniques with in this project. The theory of constraints or constraints management which is also in the lean manufacturing arsenal will be dealt with indirectly in simulation where Goldratt's six steps will be utilised to improve the system in a virtual mode and these improvements can then be translated into real and workable concepts.

Cell production is the technique where instead of having tasks on an assembly line that seem separate from one another, all the tasks are made into cells and considered departments. Each department would consist of multi skilled teams that focus on their operations which would include quality control and continual improvement. To an extent this is already the case in the Efteq assembly line but there is still space for improvement. This technique has the potential to improve efficiency because of the new levels of motivation and responsibilities as the workers share their expertise and skills.

Work place management is the proactive approach of bringing the workers closer to process and helping them to understand their personal effect on the business. This will help to create a workforce that is output conscious where each individual is responsible for keeping his/her process under control. This technique has proven to improve work ethic in the department and hence the success of the department itself.

It was realised that some of the other techniques that were reviewed steered away from the process; such things include inventory management, MRP and production scheduling.

The inventory management situation that was mentioned in the preliminary project where their stock procurement and finished goods and raw material levels was all done and managed on Excel. This was a cause for concern but it was recognized that even this section of the business could constitute a project on its own. Therefore it was decided that only suggestions would be made in this regard and theoretical ideas generated.

Production scheduling for a business like Efteq where their order frequency is far from consistent is not necessarily a problem as the largest order is in the region of 2500 and the maximum capacity of the plant is 500 per day. This has the implication that due to the order style and demand, the plant can cope with large amounts of flow and not put the business under any threat with respect to lost orders and lead time becoming a problem. If the results from the simulation study prove to increase the throughput of the system, this would positively affect the production scheduling as lead time from make to delivery will decrease in favour of the client.

8. FINAL DESIGN ADDRESS AND SOLUTION

8.1. Simulation

In order to simulate the assembly line at Efteq closely enough to represent the reality of what is going on, the following information is needed:

- The elements that make up the system
- The relationships between these elements that determine the flow of materials throughout the plant
- The time taken to perform each process
- The policies with respect to the functioning of the factory.

As described before the process is the mating of a mechanical component with an electronic component. The following brief description will give a theoretical overview of how the parts flow through the system and basically how a full water meter is assembled.

- The first part is the mechanical valve section of the plant (benches 1 to 21)
- The second part of the assembly is the electronic segment where the PC board is setup (benches 29 to 41).
- Benches 42 and 43 constitute the final assembly category.
- The mounting option is dependent on the customers' requirements and specifications (benches 45 to 51).

A detailed description of the processes that occur from bench one through to bench 51 and their respective times per unit and units per hour can be found in Appendix E.

Table 3 in Appendix F is a simplification of the production process chart and simply reflects the workers, the tasks and how many people are needed for each task. It details the amount of people that work on the processes when 500 water meters are pushed into the system in a single day. This is the maximum capacity of the assembly line and these are the conditions under which the simulation will be run.

Table 5 in Appendix F represents where the buffers are in the system and the predecessors and successors of each bench. These buffers will help keep the flow of the system at maximum and will keep processes busy that are dependent on other slower processes.

Figure 12 is a conceptual model of the factory that details the policies of the business as to how the material is handled, from scratch through to product. This image along with the time table inserted before will be the baseline from which the model will be built.

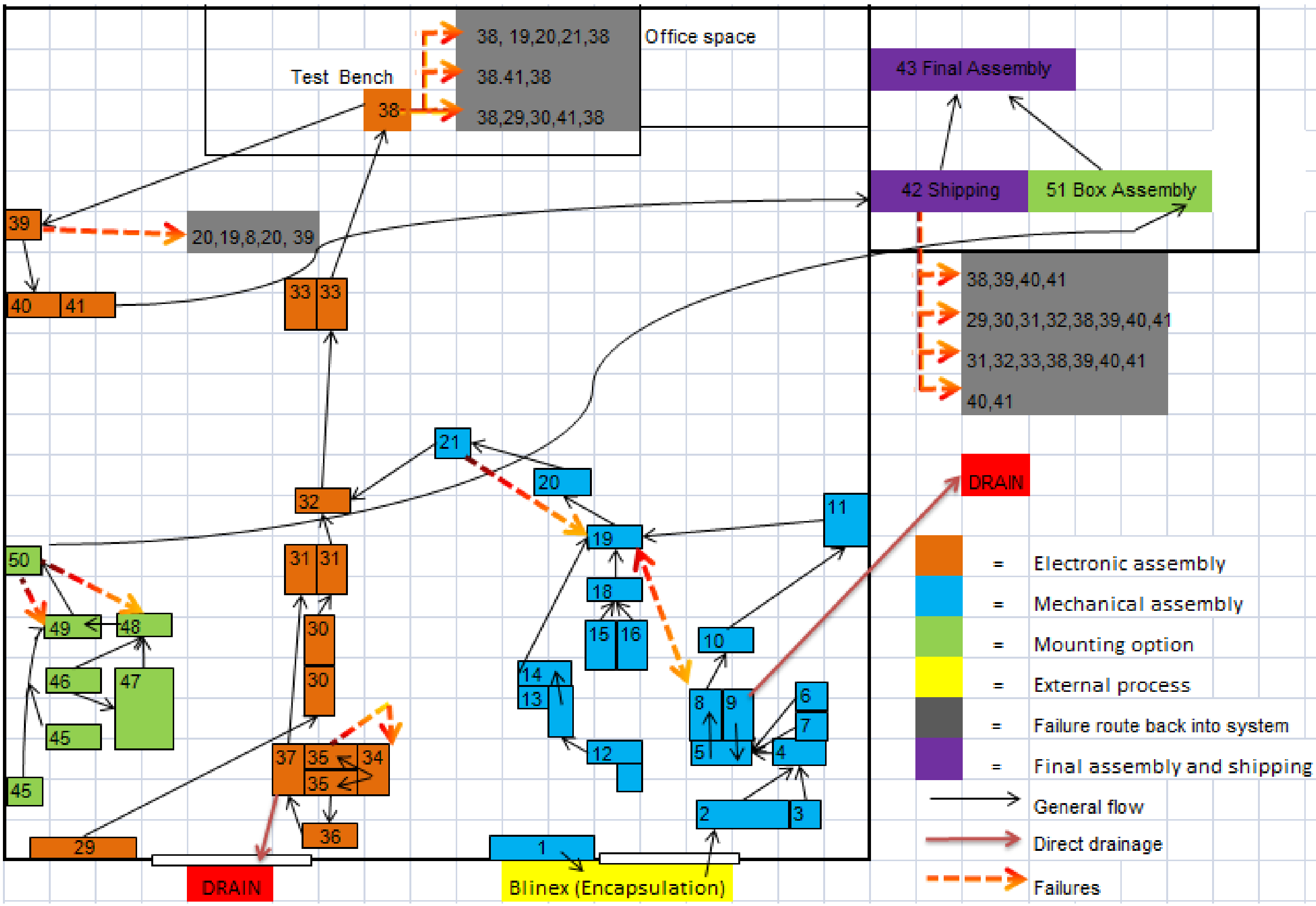


Figure 12: Current layout and material flow at Efteq

The simulation will be based on the flow as described by the above information.

This is the AS-IS stage of simulation modelling where the process as a system is replicated in a virtual setup (in the Plant Simulation interface) to represent reality as closely as possible and from this modifications can be implemented and evaluated. The complex relationships that represent the way in which materials flow through the fabrication process is the biggest hitch for the modeller as a mistake in this phase of the model design will have inaccurate implications.

To briefly revise the potential areas of opportunity, they are; resource allocation, design layout and task sequencing (includes multi skilling for workers).

The questions that the model will answer will be things like where the bottle necks are in the system, where is the heaviest flow through the lines using a Sankey Diagram, the resource utilisation as percentages in charts or plain statistics and each bench details. The what-if scenarios will include moving the layout around into cells to better the general flow of the line and making workers do more tasks in sequence to decrease the "hand – over" time.

The succeeding step is model conceptualisation where the model is built with the software and is aligned with the goals and criteria as dictated by the system specifications. The final two steps are verification and validation where verification is checking that the gap between the conceptual model and the actual virtual model is zero or within the tolerance allowed and the last step is in place to check whether the conceptual model can be substituted for the real process. These last two segments of the modelling process are critical and careful attention must be paid due to the fact that they are the most time consuming task as they will determine if the model is successful or not.

The model was built in Technomatix Plant Simulation which is essentially a modelling program used purely for manufacturing and any factory related problems and optimisations. The model and the internal processes were set out in the same fashion as the actual factory layout, this was to emphasise the flow of the material through the operations.

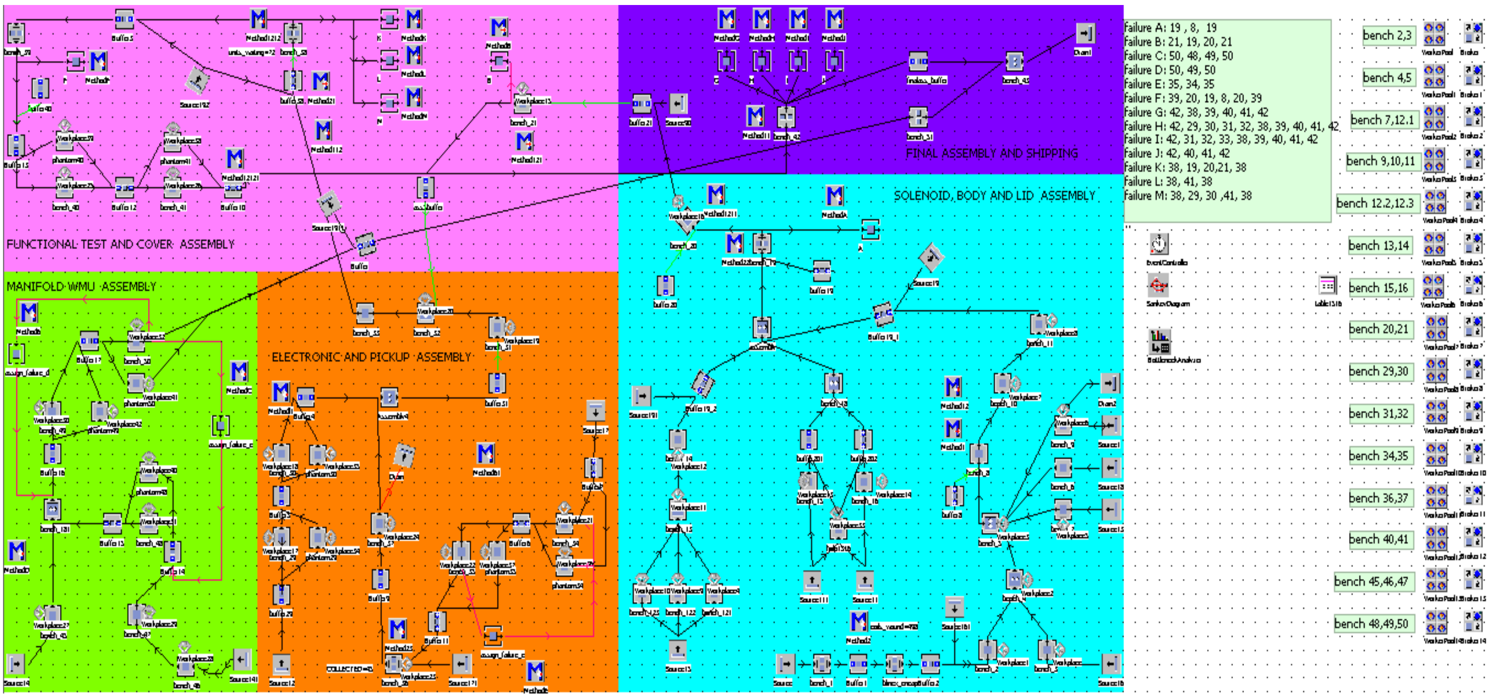


Figure 13: The assembly process modelled in Plant Simulation

Plant Simulation has a very simple but powerful and useful tool called a Sankey Diagram which indicates the material flow as a coloured line and as the frequency increases, so does the thickness of the coloured line. This shows where the bottlenecks in the system are and it can be configured that the coloured line is only drawn for a specified type of moving unit (MU), thus allowing the model analyst to understand and gain more insight into how the system is treating each part that forms the water meter.

The results obtained from the iterations of the model were that the system has parts moving around the floor and even with the Sankey Diagram activated, it is still difficult to follow the flow. It can be described as an organised mess, as these parts are thrown around the floor but end up taking the usual route through the system. The operators and the production manager obviously understand the flow of the system but may not understand how much the system could benefit if the layout was to change to a more flow friendly design.

Plant Simulation has yet another appropriate tool called the Bottleneck analyser, which is used to visualise the standard statistics of the moving unit flow (MU's) and sorts the data into a table for analysis. In addition to this it has the option of displaying, next to each bench, a graph with the levels of working (green), waiting (grey) and blocking (yellow) information. The analyser can be configured to watching any combinations of the three typical characteristics of resources, namely production, transport and storage. Detailed statistics on these resources are given to show the working, waiting and blocking times for each. From these times, it can be seen which processes are constantly busy and thus a constraint on the system and need extra labour resources, or which process is waiting for material and thus a buffer needs to be implemented and also where processes are blocking other downstream processes and could be run in parallel (depending on dependency).

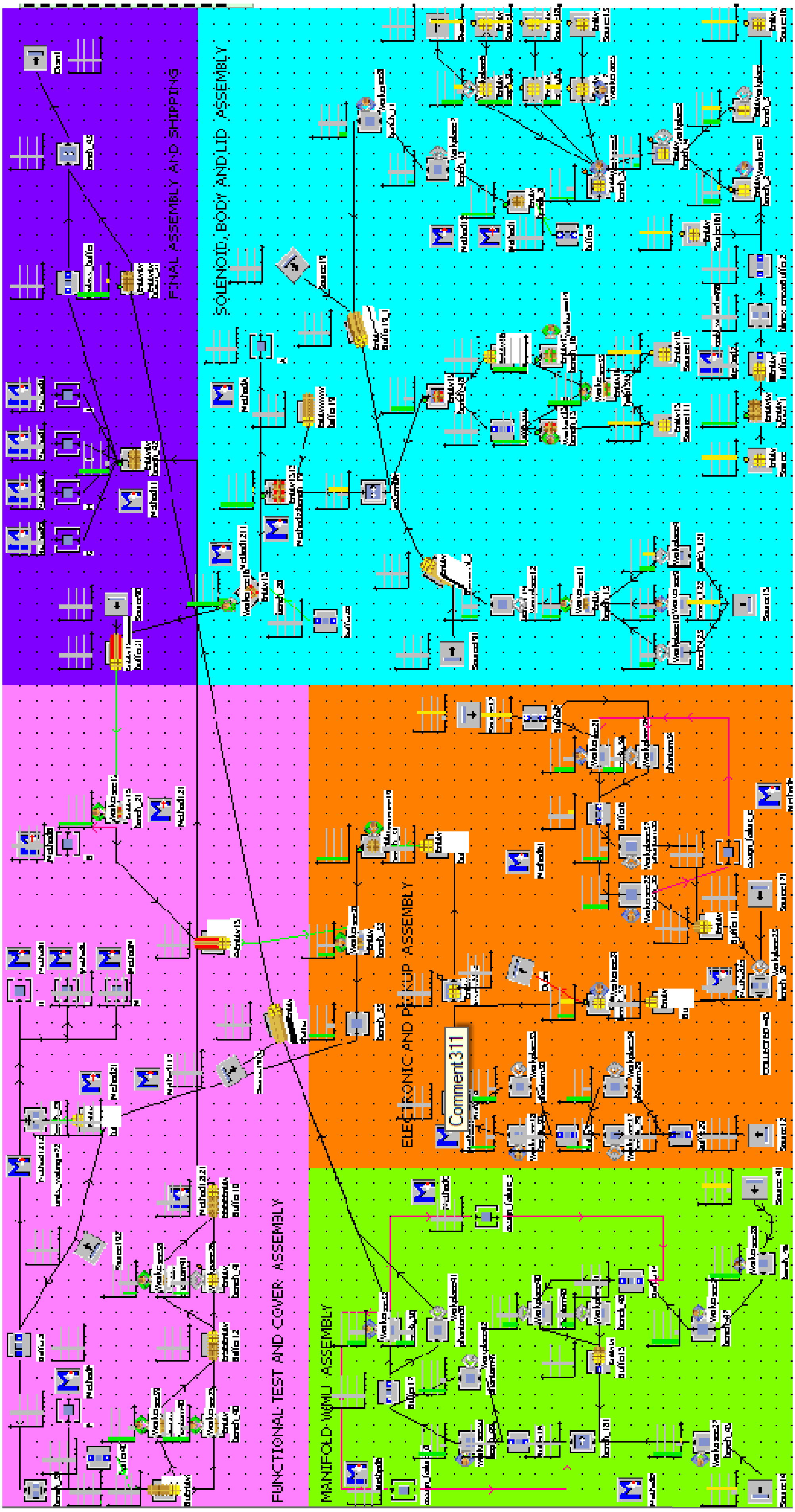


Figure 14: Bottleneck analyser output detailing bench utilisation statistics

Table 3: Worker utilisation as a percentage at the allocated benches

Bench no.	Workers allocated	Utilisation (%)	Waiting(%)	Blocked(%)
1	3	100 each	-	-
2,3	1	94.2	5.8	-
4,5	1	94.49	5.51	-
6	1	94	-	6
7,12.1	1	97	3	-
8	1	99.15	0.85	-
9,10,11	1	93	7	-
12.2,12.3	1	100	-	-
13,14	1	99.8	0.2	-
15,16	3	100 each	-	-
18	1	66.7	32.61	0.7
19	2	99.52	0.44	0.04
20,21	1	97.71	2.29	-
	1	100	-	-
29,30	1	99.72	0.28	-
	1	99.72	0.28	-
	1	98.86	1.14	-
31,32	1	75.93	24.07	-
	1	59.7	40.3	-
	1	65.12	34.88	-
33	1	98.62	1.38	-
34,35	1	89.72	10.28	-
	1	89.47	10.53	-
	1	89.93	10.07	-
36,37	1	53.67	46.33	-
38	4	4.47	95.53	-
40,41	1	98.98	1.02	-
	1	99.42	0.58	-
	1	99.63	0.38	-
42	2	99.13	0.88	-
45,46,47	3	88.03	11.97	-
48,49,50	1	89.52	10.48	-
	1	90.52	9.48	-
	1	89.77	10.23	-
	1	90.12	9.88	-
51	4	99.56	-	0.43

The table above is an indication of how each workers full 8 hours per day is divided up into completing the operation (utilisation), waiting time for when the worker is idle, and there are no parts for him to work on, and lastly the waiting time where the resource can't operate due to the fact that its waiting for another operations output for an assembly process (blocked). It is clear that there are inefficiencies and constraints in the system and these will be dealt with in the lean manufacturing section.

A buffer would not help as the work would still need to be done at some stage and obviously before hand to allow for excess stock to act as the buffer as a result the only idea is to assign more resources to these processes. The ideal solution would be to move resources from a process that does not necessarily utilise the worker to their maximum capacity provided that moving this worker does not create another bottleneck somewhere else. The simulation model was used for exactly this purpose and the results are shown in the lean manufacturing section later in the document where constraint management was used to improve the throughput for the system.

failure A: 19 , 8, 19
failure B: 21, 19, 20, 21
failure C: 50, 48, 49, 50
failure D: 50, 49, 50
failure E: 35, 34, 35
failure F: 39, 20, 19, 8, 20, 39
failure G: 42, 38, 39, 40, 41, 42
failure H: 42, 29, 30, 31, 32, 38, 39, 40, 41, 42
failure I: 42, 31, 32, 33, 38, 39, 40, 41, 42
failure J: 42, 40, 41, 42
failure K: 38, 19, 20,21, 38
failure L: 38, 41, 38
failure M: 38, 29, 30 ,41, 38

Figure 15: Failure type and route in system

The above figure shows the different types of failures and how these failures are dealt with, this is to say how the defective units are rerouted to the processes for corrective action and then the processes they need to go through to be reintroduced into the system.

The following points are an indication of the type of failure, reason for failing and the amount of components that were failed as a percentage of the total units that the bench processed.

Failures:

- A (sub standard component at bench 9): 20/990 = 0.02%
- B(not latching at pressure test at bench 21): 22/688 = 0.031%
- C(spindle off centre at pressure test at bench 50): 2/252 = 0.008%
- D(pipe leak at pressure test at bench 50): 2/252 = 0.008%
- E(reed switch setup wrong at bench 35): 5/251 = 0.019%
- F(not latching at functional test at bench 39): 11/663 = 0.016%
- G(certificate error at shipping computer at bench 42): 10/505 = 0.019%
- H(display error at shipping computer at bench 42): 10/505 = 0.019%
- I(MTS error at shipping computer at bench 42): 10/505 = 0.019%
- J(cover X error at shipping computer at bench 42): 10/472 = 0.019%
- K(valve failure at test bench at 38): 32/630 = 0.05%
- L(electronic failure at test bench at 38): 6/630 = 0.009%
- M(communications failure at test bench at 38): 19/630 = 0.03%

The total amount of re-routed parts in an 8 hour shift is 159; the only affect that this has on the system is decreasing the total throughput of the system from 475 to 462 units. This was discovered when the simulation was run for a typical 8 hour shift with no failures (zero defect system). The current defective percentage is 34.41% (159/462), yet all 462 of these units that the assembly line produces are in fully functional states as the defectives encountered are treated within the system and the re-routed through the necessary lanes to the end. These figures indicate a difference of 13 extra units in throughput if no quality assurance measures were in place and according to the current system failure percentage (34.41%) 163 units would've been passed whilst in a defective state.

Efteq management believe that every quality assurance practice that they have in place is necessary and adds value to the company. The simulation model substantiates this with the above proof that the right amount of corrective measures are in place to ensure a healthy end product. The findings were revealed to Efteq regarding their throughput to failures ratio and Efteq were content with the fact that they have enough evaluation procedures in place to produce an acceptable product.

8.2. Lean manufacturing

Most of the eight basic waste categories that hinder perfection in the value stream will be touched on as they could positively affect the system. These eight or so points are typical factors that differentiate between a system that has lean implementation and one that hasn't been reviewed with such methods. The first one is unnecessary human motions which add no value to the product or system. It is impossible to nullify this category completely as there will always be unavoidable redundant motion. The aim is to decrease these movements to an acceptable level, whether it is moving around the benches so less movement is done to hand over the product to the next department or to bring in new vices or tools to reduce the movements to perform problematic tasks. The rest of the points are:

- Waiting: material, information, people or equipment not ready (causing idle time).
  - Buffers will be used so that the processes that are quicker than their predecessors will not have to wait for parts to work on.
  - Sufficient equipment will be made available to the workers and those that have to share will have to work on another part of the process whilst waiting.
- Correction: work containing defects or errors and need to undergo a necessary step or rework.
  - The appropriate amount of quality checks are in place to allow an acceptable amount of rework. The system is completely manual and thus open to a significant degree of variation. This is to say it's almost impossible to eliminate rework as the element of human error is present.
- Over-processing: effort that adds no value. I.e. unnecessarily overshooting customers' needs.
  - The water meter that is produced does exactly what the customer needs and no more, it is a very simple function with an intelligent design.
- Over-production: producing more than what is needed. Results in too much stock on hand.
  - This aspect is related to production scheduling and will be indirectly addressed through the simulation study.
- Transportation: non value added product movement.

    - This also has the implication of the degree of material handling rising and possibly increasing the chances that a product will be damaged.
    - The layout with respect to material flow will be revised and a layout suggested thereafter.
- Inventory: materials or products waiting for orders or to become 'wanted/needed'.
    - This would be covered if an MRP study were to be carried out. This would unfortunately make the scope of this project too large for the student.
- Knowledge: people performing the tasks with sub-standard levels of confidence to perform the task at hand.
    - Sub-standard knowledge of the process leads to sub-standard products being manufactured. A study could be carried out in order to discover whether enough training has been done. The study is not entirely necessary as most of the processes are simple and do not require training but experience in the activity does help. The control charts concept mentioned earlier will also improve this aspect as the worker would work towards complying with the tasks upper and lower limits.

The theory of constraints will be a sub study in the simulation study and will follow the six steps, as defined by Goldratt, to break down constraints. Where the system will be defined in a virtual interface, the constraint will be identified through simulation runs and analysis tools, ideas as to how the constraint can be exploited will be generated, the constraint will be prioritised and the process iterated to identify the next constraint.

Numerous runs and iterations of the simulation and analysis of the standard simulation tools showed that the assembly line is very unbalanced (both from a resource utilisation and a line balancing perspective). The operations working percentages range from constantly busy (100%) to almost always idle (16.42%). Although table 3 shows the bottom two processes as 97.44 and 99 percent idle, this is not actually the case as these processes take in units in batches and process them this way and the model was not designed to tally setup time. This is due to the fact that the processes setup the units before they are worked on which means this setup time registers in the table as idle or waiting.

The idea is to take a top down approach using this table as the processes at the top with the highest utilisation figures represent the constraints to the system. Thus it will be logical to identify what could be done to or about these top processes as the final output is dependent on two of these benches which are benches 42 and 51. The only idea generated was the following:

- Increase the amount of resources available to these processes which would allow them to handle more than a single water meter at a time and will therefore allow the throughput to increase.

Table 4 is derived from the built in Bottleneck Analyser in Plant Simulation, the modelling software used, and reveals interesting statistics with respect to the processes on the assembly line and these results indicate each bench and how they are utilised in an 8 hour shift. The full table with the statistics for every bench can be found in appendix G.

The table will be the starting point for constraints analysis as a top down approach will be used to identify the constraint and then suggestion/s made to ascertain how this constriction will be exploited.

The first five benches; 1, 15, 16, 21 and the bench used for the excess parts, that benches 15 and 16 can't cope with, all have utilisation percentages of 100. This is to say that these processes are drum of the system determining the beat to which the process as a whole is defined and if more resources were to be allocated to these departments, the throughput for the system will immediately increase.

Table 4: Bench utilisation as a percentage in an 8 hour shift

resource	working	setup	waiting	blocked
root.bench_16	100.00	0.00	0.00	0.00
root.bench_21	100.00	0.00	0.00	0.00
root.bench_15	100.00	0.00	0.00	0.00
root.bench_1	100.00	0.00	0.00	0.00
root.help1516	100.00	0.00	0.00	0.00
root.bench_19	99.52	0.00	0.44	0.04
root.bench_8	99.15	0.00	0.85	0.00
root.bench_31	99.01	0.00	0.99	0.00
root.bench_20	97.71	0.00	2.29	0.00
root.bench_51	95.29	0.00	0.00	4.71
root.bench_6	94.00	0.00	0.00	6.00
root.bench_42	93.63	0.00	6.37	0.00
root.bench_46	88.03	0.00	11.97	0.00
root.bench_47	88.03	0.00	11.97	0.00
root.bench_45	88.03	0.00	11.43	0.54

There will always be a process that represents the bottleneck for the system and determines the throughput, the plan for continuous improvement in this regard is to identify the drum of the system, then implement a way in which to nullify the effect of this process on the system without sacrificing quality or important policies. Once this has been achieved there will be a new beat for the system, this new beat could be the old beat depending on the gap between the old beat and the process that succeeds it in terms of the system constraints. The process will be iterated over and over again until the system is deemed acceptable.

For the project full process studies will not be done, but the resources will be moved around from over efficiencies (processes that would usually over produce as a result of how quick the per unit processing time is) to inefficiencies, this would have the implication of the resources, namely the workers, having to undergo additional training as this strategy would introduce more multi skilling into the workplace.

The current throughput of the system, according to the constraints given by the policies of the flow and the time studies, is 462 full water meters produced in an 8 hour shift. This is lower than what is expected as the daily target at maximum capacity for the assembly line is 500 water meters per day. The model was designed in such a way to allow the easy manipulation of resources and therefore playing around with these resources and shifting them to where they are lacking had the following implications for the system:

Table 5: Modifications made to the system and their outputs

No.	Modification	Reason	Throughput
1	Current	-	462
2	Add an extra worker to aid operations 15 and 16	assumed as the drum	462
3	Add an extra worker to bench 42	Bench 42 is the drum	475
4	Add an extra worker to bench 42 and 51	Bench 51 became the drum	524
5	Take a worker away from bench 31, 32 and use the worker from 18 to help 31, 32. (i.e. 3 workers instead of 4 workers for the 3 benches)	All have low utilisation percentages (compare to current)	462
6	Same as the previous idea but includes the three assigned to 18,31,32 to perform 36 and 37	All have low utilisation percentages (compare to current)	462

7	Same as 6 but take another worker away from benches 18, 31, 32. (i.e. 2 workers instead of 3 workers for the 3 benches)	Buffers before might be sufficient	462
8	Combination of 6 and 7 where 2 workers do jobs 18,31,32,36 and 37.	Assumed the buffers could keep the flow moving.	380
9	Combination of 4 and 7. 42 and 51 receive another worker each and two workers do 18, 31 and 32.	Two optimisation concepts could collaborate	461
10	Combination of 4 and 5. 42 and 51 receive another worker each and 3 workers do 18, 31 and 32.	Two optimisation concepts could collaborate	524
11	Combination of 6 and 10. 42 and 51 receive another worker each and 3 workers do 18, 31, 32, 36 and 37.	Two optimisation concepts could collaborate	526

In the fifth initiative the workers working percentages then went up to 88.63%, 90.99 and 86.19%. This is a lot better than each in the 60's and the throughput stays constant which shows some resource allocation redundancy in this specific part of the system. The sixth initiative furthers the fifth where the one worker responsible for 36, 37 is laid off and the three responsible for 18, 31 and 32 will cover these processes. Their working percentages have now increased to 99.21%, 99.03% and 99.62% and the throughput remained constant.

The seventh initiative improves on the fifth where it is realised that the processes after the processes in question are slow enough to allow for some idle time for the workers involved. The workers utilisation percentages then become: 98.93% and 99.63%. The eighth initiative proved detrimental to the system as the throughput dropped significantly as it was assumed that the processes in question were fast enough to be operated by two workers and still ensure a constant feed to the succeeding processes.

The ninth initiative also decreased the throughput because of the worker allocation as the end processes were faster (more workers) and the earlier processes became too slow (reducing workers). The tenth initiative proved a better collaboration as the net affect was that one worker was added and the throughput increased significantly (by 13.4%).

The eleventh initiative proved a surprise as 1 worker was removed from the system and the 3 workers that were previously responsible for 18, 31 and 32 also did 36 and 37. The sought after result was that the throughput would stay relatively constant and a workers wage could be saved, yet the throughput increased as well as the wage saving. The effect of this initiative in comparison to the original system is an increase of throughput by 64 and reassigning a worker from bench 18 to aid bench 42 and reassigning the worker responsible for 36 and 37 to aid bench 51. The net effect of this alteration is no change to the workforce but a 13.85% growth in throughput.

Although it is indicated in table 3 that the four people at process 38 only work 4.47% of the time. This is not necessarily the case as these people are two testing officers and two assistants who have to be there to setup the water meters and the process measures 90 units at a time so the setup and processing requires all four present.

The rest of the workers are busy enough to not move them around and it would be unrealistic to expect 100% work rate for humans as this is literally impossible therefore it would be more practical to allow for some inefficiencies. For example those workers working 99% of the time will be over efficient by one percent which translates into five minutes extra (this is not including lunch hour).

If the concept of assigning another worker to both 42 and 51 each (reassign two workers) and training the three workers that are originally assigned to just 31 and 32 to the pool that deals with benches 18, 31 32, 36 and 37 (2 workers laid off who used to do 18 and 36 and 37 and reassigned to 42 and 51) then the number of workers in the system fundamentally stays the same but the throughput increases from 462 to 526. Although a reduction in wages would've been an additional benefit, this concept allows all the current workers to keep their jobs and not contribute towards the unemployment crisis in South Africa. The workers also gain more experience with the introduction of multi skilling which in turn promotes job satisfaction.

As a result of the solution mentioned above the systems responsiveness will increase and therefore orders will be able to be filled at a quicker rate with no addition to over head costs with respect to wages. More importantly these concepts give Efteq stakeholders additional information and options as to how they can exploit the systems natural flexibility to reduce costs and improve the system performance. This benefit translates into inventory control as Efteq will not have to rely on as much safety stock as they did in the past and that is to say that they will have less capital caught up in stock form. The initiative will also introduce a degree of multi-skilling to the 3 workers that will be dealing with benches 18, 31, 32, 36 and 37 and therefore some additional training will be required before the concept is implemented.

The above solution will be presented to the production manager at Efteq and as he knows the system on a much more detailed level, he will be able to confirm the beneficial claims of this solution.

It was mentioned earlier that a section of lean manufacturing is to look at the way in which the business handles their material and, in addition to this, how much unnecessary movement is involve in their day to day operations. Facilities planning approach was taken to develop more effective layout concepts with respect to the following aspects:

- Transportation: non value added product movement.
    - This also has the implication of the degree of material handling rising and possibly increasing the chances that a product will be damaged.
    - The layout with respect to material flow will be revised and a layout suggested thereafter.
    - Crossed process lines were avoided taking into account the flow orientations of the different assembly departments on the floor.

Below are two pictures of conceptual designs that appear more operator friendly in that they partial deal with decreasing unnecessary movement on the floor as well as material handling and hand-over time should diminish. The ideas that were used to formulate these concepts were from the Toyota production cell set up where the flow throughout each department is focussed on separately and the sequence is determined according to process progression and the downstream flow follows one direction.

The aforementioned designs were under physical constraints where some of the processes were not allowed to be moved as they are executed in a room or are products of a built in machine, the rest of the machines and tools used to process the parts are small enough to be moved without hassle. The model will not be able to prove the claims of the proposed design as the information gathered was purely the production times and not transport and hand over times and consequently it was not built for this aspect of optimisation. Only a physical movement of the benches followed with new time studies will prove the calibre of the suggested alteration.

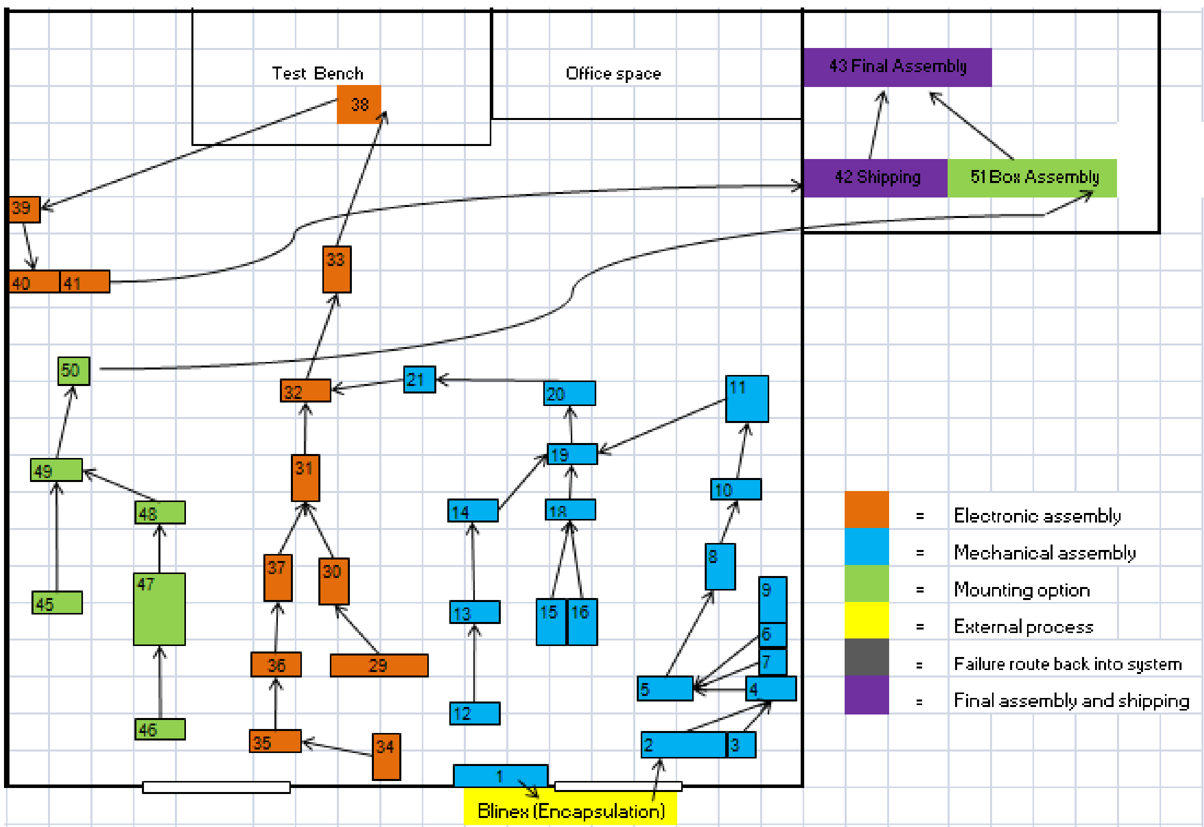


Figure 16: The first alternative layout for the system

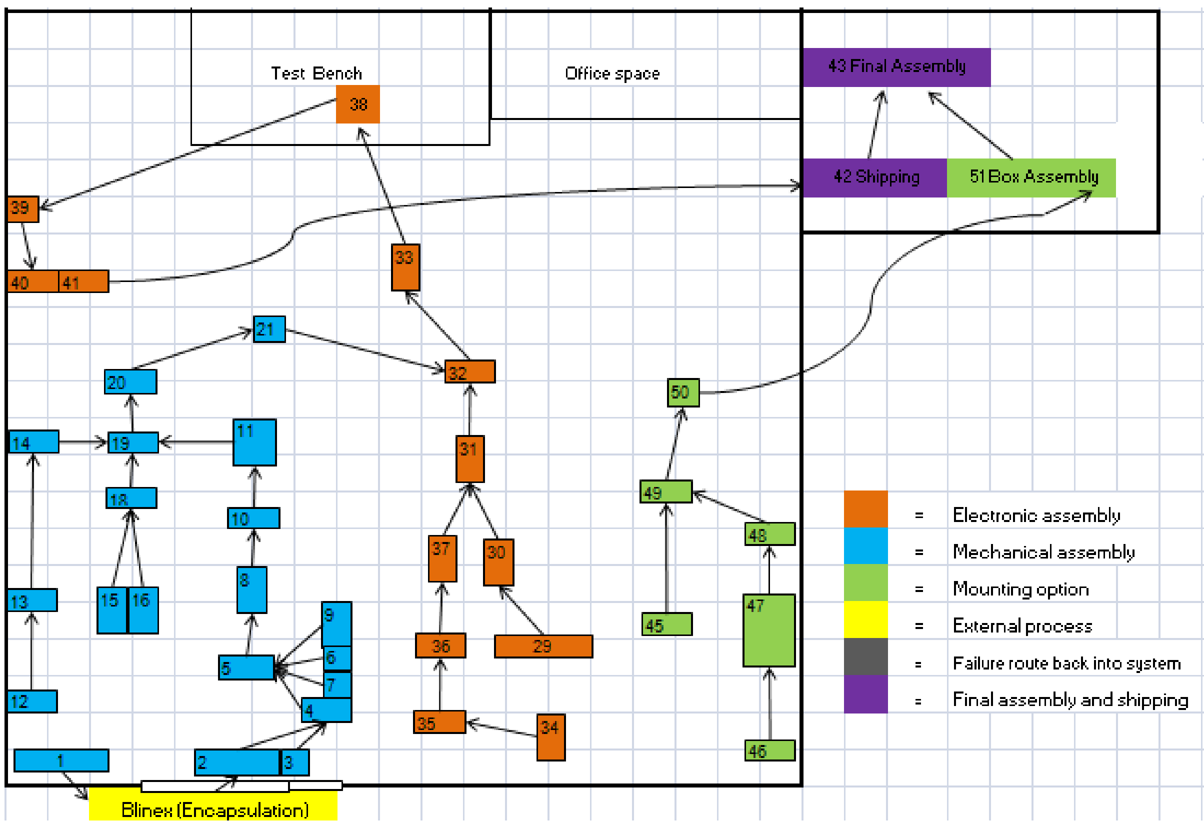


Figure 17: The second more complex alternative layout for the system

8.3. Workplace Management

The next important method identified would be to approach the business from a work place management perspective by targeting the work force as an area of improvement. The ideal way for this to work is if the labourers were to achieve or feel more responsible for the output of their individual processes. This would ultimately bring them closer to the activity that they are in charge of and push them towards a zero defect process due to the fact that the adopted mindset is that the output mainly influenced by their work.

Deming had a few ideas on how to promote exceptional workmanship and they come from his fourteen points of management. They are:

1. Share company goals with employees.
2. Drive out fear, create trust and raise employee morale.
3. Provide effective leadership.
4. Reduce conflict between departments.
5. Focus on quality rather than quotas.
6. Implement on-the-job training.
7. Work continually to improve quality and productivity.
8. Adapt to changing economic and industry needs.

The solutions developed in this segment will address all of the above points in some way with the initial goal of providing potential benefits for both employee morale and well being, and to benefit the process itself. This section of optimisation will not necessarily target only the production and assembly areas but will also focus on management as this will ultimately influence the workplace and potentially improve the work environment as a whole.

After an appointment with the production manager at Efteq, the following information was accumulated regarding the workplace policies that are already in place. A uniform goal is set for the entire workforce, this was decided by management as 10 water meters per worker per day, therefore if there are 50 odd workers, the target output for the process is approximately 500 units for that day. This target is not accurate and due to the fact that the workers do not follow the process through to the end, they are not able to check whether they have hit their target for the day except at the end of the day. The following concepts will potentially bridge the gap between worker and output and help strengthen the bond between them.

The use of control charts will do just that as any observations outside the allowable limits would be due to special variation and should be investigated to find the cause and prevent it in future. Control chart analysis would be to make sure the process is in an allowable degree of control and in the long run strive to be able to predict the system behaviour.

As a result of the strict project deadline, these charts won't be able to be implemented in the workplace and trialled for a period to gauge the effectiveness. In the long run control charts may show that because of the process capability the natural limits are not aligned with the specification limits and therefore the control charts may be out of spec and/or lopsided. This would call for a process capability study to be done and the specifications adjusted or the process itself modified. These charts also have the ability to decrease quality costs.

The purpose of these charts are to detect small changes in the actual process (the processes specific to Efteq will be the test benches and the reed switch setup) and not necessarily the product (although it does translate into the output of the process). When a change is detected, it is classified into either a good or bad change, the bad cause should be found and eliminated whilst the good cause should be identified, evaluated and may even be set as the new way of working. This is another way of charts adding to the continuous improvement incentive that all businesses should have in place to ensure control and competitiveness in their market.

If the workers take record of all the parts they receive that do not conform to what is required by the process, these records can be used to evaluate how reliable the supplier is. From this a study could be launched to determine why the supplier is supplying sub standard products and notify them accordingly or if the company should find another source. The other option would be to log these non conformances in a document and quarantine the parts and send them back to the supplier for a reimbursement or replacement, this would save the company on scrapping costs and improve the traceability of these items.

The workers possess the best relationship with the system and therefore each worker should be issued an evaluation form every 2-3 months (or whenever deemed necessary) where they can voice their opinion of how they would improve their own process or what they would like to see changed in their workplace. This is part of the Kaizen attitude towards the workplace where the workers are responsible for two things which are doing the job and looking for ways to improve it. A simple example of such a form is shown in the accompanying figure:

Process Improvement Questionnaire		
General		
Name:		**DATE:**
Bench Number:		
Task Description:		
Raw Materials required:		
Tools required:		
Idea Generation		
Problems Experienced with the process:		
Additional tools required:		
Improvement ideas:		

Figure 18: Process improvement questionnaire

CONTROL CHART DOCUMENT												
Bench No.			DATE:									
Operator/s												
Quality characteristic												
Sample size					Batch size							
Upper control limit					Lower control limit							
observations	1		21		41		61		81		101	
	2		22		42		62		82		102	
	3		23		43		63		83		103	
	4		24		44		64		84		104	
	5		25		45		65		85		105	
	6		26		46		66		86		106	
	7		27		47		67		87		107	
	8		28		48		68		88		108	
	9		29		49		69		89		109	
	10		30		50		70		90		110	
	11		31		51		71		91		111	
	12		32		52		72		92		112	
	13		33		53		73		93		113	
	14		34		54		74		94		114	
	15		35		55		75		95		115	
	16		36		56		76		96		116	
	17		37		57		77		97		117	
	18		38		58		78		98		118	
	19		39		59		79		99		119	
	20		40		60		80		100		120	

Figure 19: control chart document used for data capturing for control charts

The preceding figure is a document that the worker can fill in whilst on the job by taking a sample of product and recording a specific qualitative characteristic under observations. These recordings can then be translated into control charts where the process can be further analysed. The control chart recording process can be repeated as frequently as is necessary depending on what the results yield. The documents can be printed out and issued to the employee to be entered into an Excel sheet, at a later stage, which would generate the control chart from the information. Another option is to laminate an A1 blank chart and plot the points manually with a whiteboard marker, this would allow the worker to easily observe the output of his/her process.

These documents can be used at benches 35 and 38. Bench 35's process is where a reed switch is calibrated manually and used to read changes in magnetic orientation and if out of limits, the water meter will not function properly. An X bar and S chart can be used here where the sample size is larger than ten and thee charts will be able to monitor the process standard deviation as well as the process mean.

Bench 38 is a big testing area where 90 units are tested simultaneously, they each have 3 types of flow put through them (trickle, medium and high) and a behaviour curve is drawn from the results, the same flows are put through them again and the new curve is compared with the old one. The allowance is 10% where if the deviation between the two curves exceeds 10% then the unit is sent back into the floor to be repaired. An np or c attribute chart can be drawn up from this document in the form of a go or no-go analysis supervising the number of non-conformances found during the testing of each unit. It is rare for a unit to experience more than one non-conformance but a separate u-chart will be able to record how many units are flagged with more than one defect. Consequently if the findings are a reason for concern then a study into the causes can be initiated and the appropriate actions followed to prevent further occurances.

In addition to the Kaizen outlook, Ishikawa for the purpose of defect prevention or process improvement could be introduced along with the questionnaires. The worker would be able to identify the problem or the opportunity and give reasons for why the problem has occurred. These questionnaires and diagrams will be reviewed, prioritised and the main problems will be brainstormed using the information from the questionnaires to find appropriate solutions. This new policy would empower the workforce even more and at the same time give management feedback on how the process is behaving.

These improvements include:

- People: involved with the process
- Methods: How the process is executed and the precise requirements for doing it, such as policies, procedures and regulations
- Machines: Any equipment, computers, tools required to complete the job
- Materials: Raw materials, parts, pens used to create the final product
- Measurements: Data generated from the process to assess its quality
- Environment: The conditions, such as location, time and temperature.

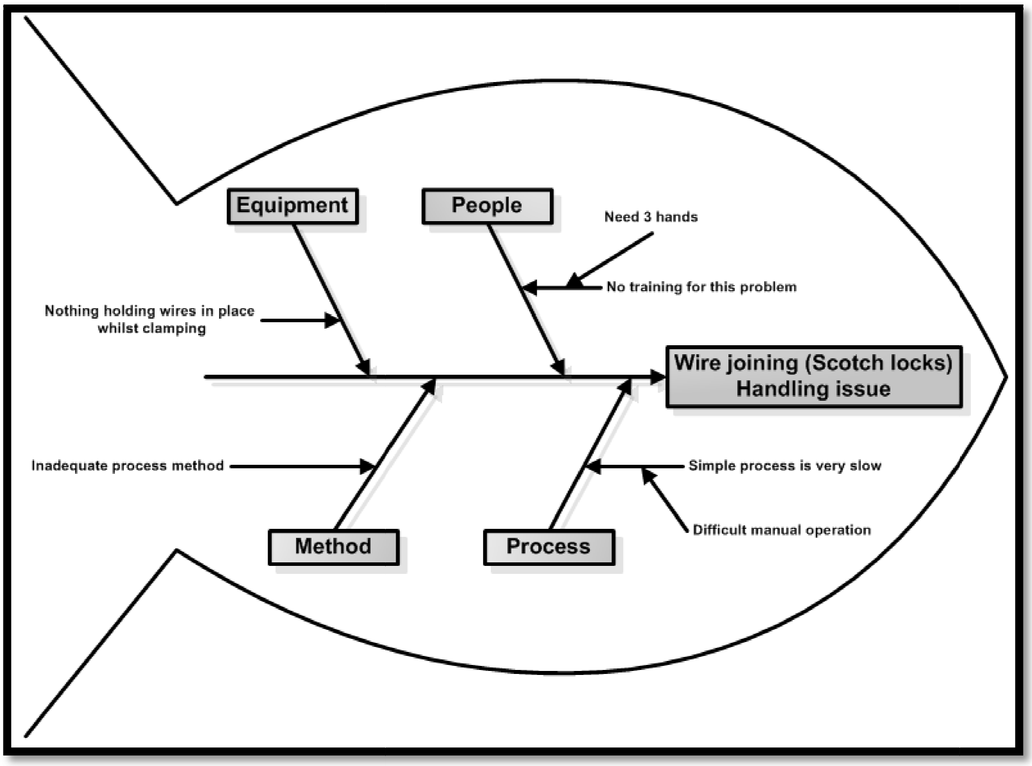


Figure 19: Scotch lock handling issue n fish diagram form.

The problem that was identified, using the above diagram, was the handling of wires when it came to joining wires together in a capsule called a scotch lock. The problem that the workers experienced was holding both wires together in the right orientation then having to put the lock on the two wires and then clamp it closed to secure the wires (figure 20). There were two simple solutions that were generated; the first was to design a jig that holds the wires in place whilst the worker clamps the lock and the second was a simple hand held pliers device that holds the wires and the worker can then clamp the lock using his free hand.

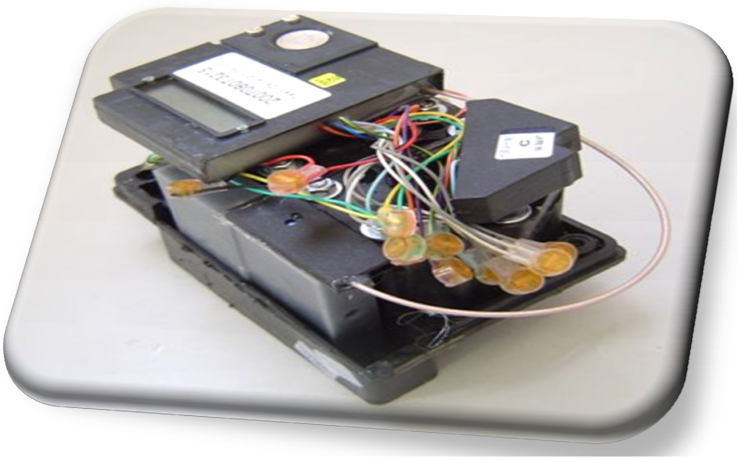


Figure 20: The electronic part of the meter with the many scotch locks on the ends of the wires

The final initiative that will be proposed will be the check sheet. The check sheet is a very simple document that is typically used to collect quantitative or qualitative data easily and efficiently. The use for this type of tool at Efteq will be for raw parts that cannot be used before the process has started, this would allow the operator to keep a tally of how many parts were faulty and how these parts can be quarantined for replacement to reduce the costs of scrapping or improper recording methods as a result of bad reconciliation. There are many other uses for these types of documents and collecting information for control charts is one that will be highlighted. Here are 5 basic types of check sheets and instances of where in Efteq they could be effective are included:

- Classification: An attribute such as a defect or failure mode must be classified into a group.
    - This sort of check sheet would be useful at benches 38, 42 to classify the form of failure encountered and these failures can be investigated if there are irregularities in frequencies of their occurrences. (Figures 21 and 22)
- Location: The physical location of a trait is indicated on a picture of a part or item being evaluated.
    - This kind of check sheet could be used with a sticker system as proposed by the student where each sticker colour has a significance of the different route that the defective unit needs to follow. The check sheet is then tallied (at the end of the period) according to the default amount of stickers on a sheet minus those remaining on the sheet as seen in figure 23. In this way only the necessary processes will be repeated and with a single glance the worker will know where to send the unit.
- Frequency: The presence or absence of a trait or combination of traits is indicated. Also number of occurrences of a trait on a part can be indicated.
    - Any bench at Efteq could utilise this as proof of the throughput per their operation and would allow them to continuously check whether their process is on schedule for the throughput needed.
    - The plastic cover that closes the water meter comes from a mould, if this mould was altered to incorporate a table with the process/bench number as shown in figure 24 and each worker, after completing their task, can check their box with silver permanent marker and send it on. The traits being

observed here are whether all the necessary processes themselves have been completed.

- Measurement Scale: A measurement scale is divided into intervals, and measurements are indicated by checking an appropriate interval.
    - These check sheets are useful as they can be translated into the control charts as described earlier and can be applied to benches 15, 21, 38, 39 and 50 where ever there is a test bench where an output or status is recorded.
- Check List: The items to be performed for a task are listed so that, as each is accomplished, it can be indicated as having being complete or incomplete.
    - This form of check list is impractical as it would have to be passed down from process to process for it to record what it's supposed to. The product turnover at Efteq is too high to have one check list per unit and therefore the concept of the mould encompassing a task completion sheet was suggested.

Check sheets provide an easy control mechanism in the assembly as not all of the units will follow the same route through the system and hence traceability becomes an issue.

Classification check sheet							
Name of data recorder							
Location							
Data collection dates							
Bench No. and description							
Defect type	Days						TOTAL
	Mon	Tue	Wed	Thur	Fri	Sat	
Certificate error							
Display error							
MTS error							
Cover error							

Figure 21: Classification check sheet for bench 42

Classification check sheet							
Name of data recorder							
Location							
Data collection dates							
Bench No. and description							
Defect type	Days						TOTAL
	Mon	Tue	Wed	Thur	Fri	Sat	
Valve failure							
Electronic failure							
Communications failure							

Figure 22: Classification check sheet for bench 38

Location and frequency check sheet (sticker system)							
Name of data recorder							
Location							
Data collection dates							
Bench No. and description		42	Shipping computer check				
DEFECT/FAILURE TYPE							
Certificate		**Display**		**MTS**		**Cover**	
Route		**Route**		**Route**		**Route**	
38		29		31		40	
39		30		32		41	
40		31		33			
41		32		38			
		33		39			
		38		40			
		39		41			
		40					
		41					
TOTAL	48		48		48		48

Figure 23: Location and frequency check sheet for bench 42

Task Completion template							
1		15		28		42	
2		16		29		43	
3		17		30		44	
4		18		31		45	
5		19		32		46	
6		20		33		47	
7		21		34		48	
8		22		35		49	
9		23		36		50	
10		24		37		51	
11		25		38			
12		26		39			
13		27		40			
14		28		41			

Figure 24: Task completion template that could be imprinted using a mould

The results from the check sheets that explore the defect type frequency can be further analysed to find out reasons for the defects occurring. New observation sheets listing the causes of each defect can be designed and the frequency recorded. In this way management can figure out how to approach the problem and decrease or nullify the cause.

All these workplace efforts are to bring the workers closer to the process, give them a higher level of responsibility and a better understanding of what they mean to the system. The new workplace policy that will encompass the above ideas will focus on numerous methods of continuous improvement through employee involvement and satisfaction on both assembly and management levels. To review, the policy will incorporate:

- Training in control charts, the use of Ishikawa diagrams and how they are used along with the questionnaires to find new ways of improvements and to understand the process better.
- Check sheets issued to the relevant benches to improve control over the materials and processes.

If management finds it more effective, instead of providing training in Ishikawa diagrams, these can be used as sub categories when filling out the process improvement questionnaires in order to cover all the relevant aspects of the processes.

8.4. Inventory management

The inventory side of the company that ranges from stock procurement to finished goods inventory levels is a project on its own. Thus it was decided to simply generate ideas as to how the situation would be handled.

The main idea would be to start from scratch and put into practice an MRP system as this would suit the push type production policy. However, because of the responsiveness of the system, the business does not necessarily need to keep high levels of finished goods waiting for orders and taking up space in the warehouse and binding capital in goods.

The procurement of raw materials is a different aspect of the business altogether as there are many components in one water meter and the procurement of these have different lead times as they originate all over the world. There should be a different procurement policy for each. The way to go from here would be to develop a classic and simple planning system where old records would be used to see the demand and how many of what was needed for the production runs in order to satisfy the demand. From this, a master schedule can be made to meet the demand and a document produced that would detail how much is needed for different size demands and when it is needed simply by using the forecasted values. The only downfall for this type of planning tool is that it is completely dependent on how accurate the old records are and that it‘s going to remain relatively constant.

The measures of interest that the method will assist with falls under three categories namely; the smoothness of the production outputs, the safety stock and the stability of the production plan. The aim for all of these outputs is to decrease the amount of variance present in each and in doing so gain a form of control over the process. Safety stock will concentrate on how much inventory to carry in order to satisfy demand on time yet keep stock at a minimum to save additional unnecessary carrying costs.

9. CONCLUSION

Simulation is one of the most powerful tools that an industrial engineer can invest in. It has the ability to move virtual mountains and is key to the backbone of this project attributable to the fact that most of the other techniques worked together or used simulation to prove their plausibility.

Efteq could benefit from the results of this study provided the necessary steps are followed towards implementing the concepts. In short this project would allow Efteq to increase the throughput (almost 10.5 water meters per person per day instead of ten for a workforce of 50) for their system with no extra labour costs or implications. The best initiative that was run by the simulation translates into a 13.85% increase in throughput with workers assigned to more than one task but a net effect of the workforce size remaining constant. The simulation model and the outputs achieved allows Efteq to explore the flexibilities of their system and push the boundaries in terms of the general "waste" reduction in the pursuit of a lean system.

The project adds a new interface between the physical workforce and management with the help of the above mentioned workplace management techniques including a way forward towards a continuous improvement program that values the worker opinion. There are so many pathways throughout the system as observed by the Sankey Diagram and not all products follow the same route. The check sheets create a visual form of control in that they allow workers to identify, from a glance, where the unit should be as all of the failures can't be seen with the naked eye.

The fishbone (Ishikawa) diagram is a proven problem analysis technique used by management to deal with problems on the process line and the questions it asks helps to find a deeper cause of the problem. The template diagram looks at the problem from all important aspects and suggests ideas of causes that might not seem obvious and are thus overlooked. It functions well as a brainstorming tool for solutions as the causes for the problem are eliminated one by one.

Efteq is a young manfactring business and thus have a long way to go in terms of running an efficient and streamlined setup. The project addresses some of Efteq's areas of concern and feasible solutions have been proposed to improve the operations of the business.

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APPENDICES

Appendix A: list of processes

Table 6: Bench number and process name

	Processes		
1	Coil Winding	29	Tag Reader Preparation
2	Body Drilling	30	Tag Reader Assembly
3	Rotor Support Assembly	34	Pick-up wire solder + Magnet Insert
4	Rotor Support Ultrasonic Welding		
5	Solenoid Assembly	36	Pick-up Potting
6	Core Assembly	35	Pick-up Reed Switch solder + Setup
7	U Bracket Shape	31	Electronic Assembly
8	Solenoid Soldering		Pick-up Cleaning & QC testing
9	Solenoid Megger	37	Re-programming
10	Potting	32	Meter Assembly
		40	Amtenna Prep/Assembly
11	Curing Oven	38	Test Bench
12	Lid Drill, Clean, cut groove, clean oortjie	39	Functional Test
13	Lid Bearing assemble, Portpipe, Oortjie	41	Cover Assembly
14	Lid Diaphragm assemble, press flowring	45	Pipe cutting + chamfer + elbow
15	Rotor Assemble	46	Spindle Prep, NRV Prep, Grease
16	Plunger Assemble	47	Nut and NRV to manifold assembly
		48	Pressing spindle into body
18	Plunger Setup	49	Manifold Ass., Pipe/Manifold Assembly
19	Valve Closing + Blowing	49	Elbow align & tighten
20	Torque Closing + Torque		
		50	Pressure Testing

Appendix B: The current layout of the assembly line

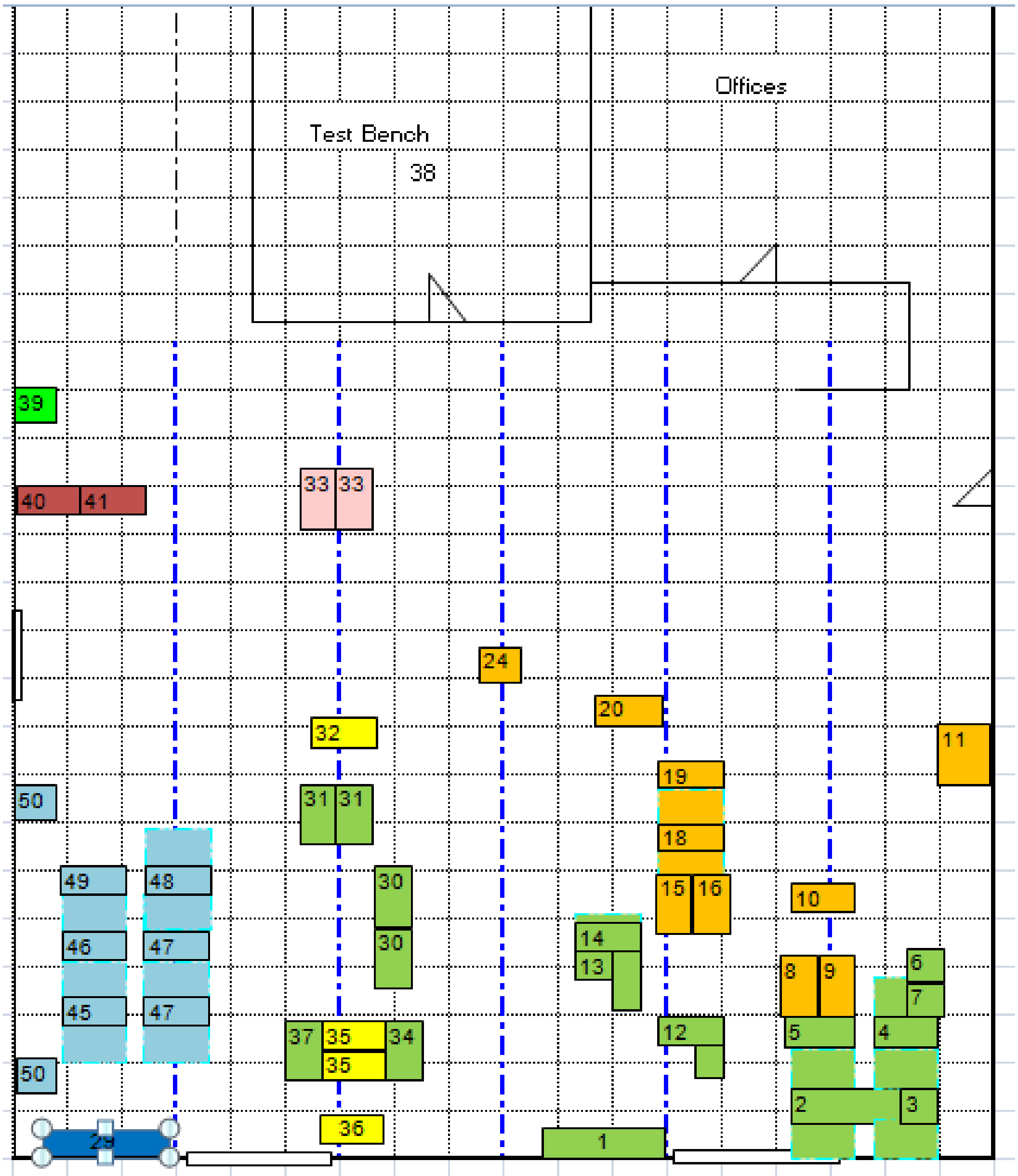

Figure 25: Current layout

Appendix C: The assembly process:

The assembly process is very simple as it basically comprises of a mechanical valve assembly being married to and electronic assembly, the following explanation is a brief overview of what the water meter comprises of and when the components come together:

1. The first part of the final assembly is the mechanical valve assembly. This contains the solenoid, the rotor, the plunger and the diaphragm to hold the parts.
    a. The solenoid is manually wound by an operator, sent to an outside company to be encapsulated (Blinex). When a current is passed through the solenoid it magnetises the plunger and opens the valve to allow for water flow using a high-low pressure system discussed later.
    b. The plunger is attached to the diaphragm and the solenoid induces a magnetic field which temporarily allows the material to be magnetised which causes the valve to open and close according to the solenoid activity.
    c. The diaphragm is designed so that when water enters it, a vortex is created and it spins a rotor and runs up the counter, the rotor sits on a glass bearing to minimise friction. This rotor contains a magnet that is fixed on its axis and is set at a horizontal orientation with the north and south poles extending outward. A fork shaped sensor is placed around the axis of the rotor so that when the rotor spins the sensor (reed switch) will record the change in the magnets north and South Pole direction and from this; pulses are sent to the electronic board and are converted into water usage readings.
    d. The valve is then hooked up to a testing bench where pressures between 5 and 10 bar are sent through it to test functionality.
2. The PC board is the electronic component that translates the pulses from the sensor into information.
    a. The pins are fitted to the board, and an extra wire is used for speaking to the board during the testing times.
    b. A meter removal tamper (MRT) is fitted to the board to ensure that if the user intends to mess around with the water meter or to steal water that the system will go into a special mode and prohibit further activity.
    c. Because the water meter has magnets inside it, introducing a strong magnet within ten centimetres will affect the reading (even though it is a fraction of a

percentage.) thus according to the SABS standard a magnet tampering system (MTS) is installed which shuts the system down temporarily if an outside magnet is introduced, if this is done more than five times the valve is permanently shut down and can only be reactivated by a technician. The SABS were the party responsible for enforcing this countermeasure.

d. The board is then uploaded with specific software and an antenna is added so that wireless communication with each water meter is allowed

3. Next is the calibration of the water meter where three different rates of water flow are sent through it called; trickle flow (lifeline flow), nominal flow, and maximum flow. The results form a curve and the water meter is fitted to the curve, then it is run again and the second run is compared to the original curve and if there is a deviation of more than one percent then the water meter is deemed inconsistent and will need rework.
4. An electronics test is done to make sure all is working and then a magnet test is done to check the functionality of the MTS. Now the assembly of all the above components is known as a half meter.
5. The half meters wait until an order comes through for shipping then it is tagged, from this plus minus 250 values that describe the unique water meter are recorded on a computer, this will verify that it is the right meter for the order. The manifold is connected to the half meter and is the part that connects the inlet pipe to the meter and also the outlet pipe to the meter. This manifold has a non return valve and a manual shutoff valve. The half meter sits on top of the manifold and the manifold is placed into a casing. There are three different casing configurations that can be assembled from this point and depend entirely on what the customer is looking for. They are; a wall mounted unit, a long boxed unit, a short boxed unit and lastly a stand pipe unit. After this final assembly the product is now a full meter and ready for distribution.

The meter is equipped with a manual shutter pipe that opens and closes the valve. A stainless steel tag is used by the customer to talk to the meter and contains the pre paid information specific to each tag holder.

Appendix D: Simulation (Assembly) friendly processes [time studies]

Table 7: Process information

Process	Sub task activities	Batch time (s)	Batch size	Time per unit	Person allocated	Bench no.
Solenoid	Load spool and secure	10	1	10	1	One to five
	Secure copper wire	14	1	14	2 (50%)	
	Wind spool	30	1	30	1	
	Stop drill and cut copper wire	8	1	8	1	
	Secure end around pipe and remove jig	18	1	18	1	
	Twirl copper wire and unload solenoid	10	1	10	1	
	Cut heatshrink	4	1	4	2 (50%)	
	Put on heatshrink and apply heat gun	14	1	14	2	
	Bend pipe with pliers	12	1	12	2	

Process	Sub task activities	Batch time (s)	Batch size	Time per unit	Person allocated	Bench no.
Body assembly	Rotor support assembly	190	10	19	1(31%)	Six to eleven
	Trim body	134	10	13.4	1(75%)	
	Body drill preparation - Packing	128	40	3.2		
	Drill hole into meter	175	40	4.4		
	Stack drilled bodies on table	36	20	1.8		
	Unload drilled bodies + clear hole	162	20	8.1		
	Insert rotor support into body	153	10	15.3		
	Ultrasonic weld rotor support to body	101	10	10.1	2(30%)	
	Label body and throw in bin	61	10	6.1		
	Arbor press pivot into rotor support	1	1	1		
	Bend U-bracket - arbor press jig	70	10	7	2(62%)	
	Spread open U-bracket with pliers	24	10	2.4		
	Assemble core and check specs	107	10	10.7		

	Trim solenoid ring	161	10	16.1		
	Cut + trim solenoid (prepare)	127	10	12.7	3(56%)	
	Clean solenoid wire	121	10	12.1		
	Setup megger test	95	192	.5		
	Load solenoid	148	32	4.6		
	Test solenoid	86	32	2.7		
	Unload solenoids	52	32	1.6		
	Clear meggertest	58	192	.3		
	Insert solenoid into U-bracket	30	10	3	4	
	Insert core into solenoid**	34	10	3.4		
	Push sol (with front plate) into body	160	10	16		
	Press solenoid into body + check specs	84	10	8.4		
	Insert solenoid ring	110	10	11		
	Load bodies for polarity test	30	10	3	5	
	Polarity test	201	10	20.1		
	Cut heatshrink	600	1000	.6		
	Load bodies and prepare wire for soldering	33	6	5.5		
	Apply solder	38	6	6.4		
	Solder yellow wire	55	6	9.2		
	Solder green wire	45	6	7.5		
	Apply heat shrink	50	6	8.3		
	Potting prep - Bend wire	180	10	18	3(46%)	
	Pack bodies in oven - potting	50	10	5		
	Mix potting compound	171	60	2.9		
	Pot bodies	118	60	2		

Process	Sub task activities	Batch time (s)	Batch size	Time per unit	Person allocated	Bench no.
Lid assembly	Trim Port Housing	60	10	6	1(12.8%)	Twelve to thirteen
	Trim Flow ring	40	10	4	1(8.5%)	
	Cut groove in lid	35	5	7	2(60%)	
	Trim burrs at Port Housing Area	106	5	21.2		
	Trim Bearing holder	60	10	6	1(76%)	
	Glass to bearing holder to lid assembly	150	10	15		
	Port Housing. PH Dia, MSP to lid	150	10	15		
	Diaphragm to lid and press flowring	190	10	19	2(40%)	

Process	Sub task activities	Batch time (s)	Batch size	Time per unit	Person allocated	Bench no.
Lid assembly	Trim rotor base + check for concentric hole	3600	500	7.2	1	fifteen
	Insert magnet into rotor and align	55	5	11		
	Insert rotor bush into rotor	86	5	17.2		
	Insert pivot into rotor	91	5	18.2		
	Check if rotor spins uniformly	25	5	5		

Process	Sub task activities	Batch time (s)	Batch size	Time per unit	Person allocated	Bench no.
Plunger assembly	Press lever straight	40	5	8	1	Sixteen and eighteen
	Press washer onto plunger	45	5	9		
	Bend lever for plunger assembly	38	5	7.6		
	Attach lever to plunger	42	5	8.4		
	Bend lever on plunger	42	5	8.4		
	Attach diaphragm to plunger	38	5	7.6		
	Fit tube and cut off excess	70	5	14		

Process	Sub task activities	Batch time (s)	Batch size	Time per unit	Person allocated	Bench no.
Valve assembly and testing	Fetch bin	60	24	2.5	1	Nineteen to twenty-one
	Fit rotor	30	12	2.5		
	Measure and Insert Spring	5	1	5		
	Insert Plunger	8	1	8		
	Setup	18	1	18		
	Place lid	15	1	15		
	Place valve on stand	5	1	5	2	
	Press down lid	5	1	5		
	Place and fasten 4 nuts	28	1	28		
	Remove previous valve	5	1	5		
	Place new valve on blow jig and blow	10	1	10		

	Place valve on stand	5	1	5	3	
	Place and fasten 6 nuts	45	1	45	4	
	Fit MRT washers and fasten	35	1	35		
	Torque 12 nuts	20	1	20		
	Remove valve from stand	5	1	5		

Process	Sub task activities	Batch time (s)	Batch size	Time per unit	Person allocated	Bench no.
Electronic and pick-up assembly	Stack pins (negative)	101	32	3.2	1	Twenty-nine to thirty-three and thirty-four to thirty-seven
	Insert soldering wire	30	10	3	2	
	Preparation - Strip wires	14	3	4.6		
	Pickup, loosen and weave PCB wires	95	3	31.6		
	Weave wires together 2x	22	1	21.9		
	Dip wires into solder pot	47	5	9.4		
	Trim wires	36	5	7.2		
	Attach pins (negative)	224	10	22.4		
	Get PCB and cut wire to size	5	1	5	3	
	Insert solder into pin (positive)	120	10	12		
	Solder tag reader pin (positive)	120	10	12		
	Arbor press pins into PCB	125	5	25		
	Fill Neg pin holes with silicon	10	1	10	4	
	Apply silicon around neg pins	7	1	7		
	Insert cover plate	7	1	7		
	Cut MTS wires to size	20	5	4	5	
	Sort Pick-up wires	5	1	5	6	
	Connect pickup	55	1	55		
	Sort MTS wires	5	1	5		
	Connect MTS	45	1	45		
	Install battery + insert cap & pickup	200	5	40	7	
	Connect solenoid + battery to PCB	575	5	115	8	
	Check - power tag	25	5	5	9	
	Reporgramming setup + connect	111	6	18.5	10	
	Magnet on jig	35	6	5.8		
	Reporgramming	275	10	27.5		
	Remove + unload	26	6	4.3		

Process	Sub task activities	Batch time (s)	Batch size	Time per unit	Person allocated	Bench no.
Manifold and WMU assembly	Trip O-ring holder + Non Return	60	10	6	5(12%)	Fourty-five to fifty-one
	Apply Grease to spindle	100	10	10	1(95%)	
	Insert o-rings onto spindle	270	10	27		
	Insert spindle seats	50	1	5		
	apply grease to outside of o-rings	6	10	6		
	Insert 2 M6 nuts into manifold	150	10	15	2	
	Insert T-piece into NR valve	110	5	11		
	Insert NR valve + holder + o-rings	125	10	25		
	Fit retainer ring 0-ring to manifold x2	170	5	17	3	
	Insert spindle into manifold	70	5	14		
	insert grub screw	80	5	16		
	Final manifold testing	250	5	50	4	
	Locate MWU box and fasten 3 screws	145	5	29	5(92%)	
	Fit split ring, 2x compression nuts to manifold	80	5	16		

Process	Sub task activities	Batch time (s)	Batch size	Time per unit	Person allocated	Bench no.
Functional test	Load + clamp meter	70	6	11.67	1	Thirty-eight and thirty-nine
	Test meter(functional - system tags)	156	6	26		
	Sticker meter	15	6	2.5		
	Unclamp + unload	60	6	10		

Process	Sub task activities	Batch time (s)	Batch size	Time per unit	Person allocated	Bench no.
Cover assembly	Prepare Antenna - Add solder	70	10	7	1	Fourty-five to fifty-one
	Load meter	15	5	3		
	Trim wire	25	5	5		
	Add solder	25	5	5		
	Cut wire	12	5	2.4		
	Add heatshrink	12	5	2.4		
	Solder antenna + heatshrink	103	5	20.6		
	Place MTS and Antenna	12	1	12		
	Unload meter	15	5	3		
	Take meter, neaten TR wires, put on jig	135	5	27	2	
	MTS & MRT test	130	5	26		
	Unload meter	15	5	3		
	Take meter & neaten wires	105	5	21	3	
	Place Dust cover	35	5	7		
	Place cover and fasten selftappers	105	5	21		
	Apply power tag	30	5	6		
	Unload meter	15	5	3		

The box assembly process is when the pipe, elbow, level and final assembly occurs; this is performed by one person and is only completed once the customers' demands are known. The shipping process is executed using the shipping computer and is also only done when the customer order comes through.

Process	Sub task activities	Batch time (s)	Batch size	Time per unit	Person allocated	Bench no.
Final assembly WMU	Ship meter	400	10	40	1	Fourty-four
	WMU Box in Holder	15	5	3	2	
	Meter on box	20	5	4		
	Fasten 1 capscrew	40	5	8		
	Check with MRT tag	25	5	5		
	Pack meters in Box	20	5	4		
	Add loose components and tape box	60	24	2.5	2	
	Glue box number	20	1	20		
	Take box away and stack	60	24	2.5		

Appendix E: Theoretical flow of product through the system

Mechanical assembly

- Bench 1: burrs cleaned off the spools, then they are prepared for coil winding, then coil winding occurs. These coils are then sent to an external company called Blinex for encapsulation
    - Note that operations 2 and 3 feed operation 4 and run parallel to one another
- Bench 2: the body of the mechanical valve is then drilled and cleaned.
- Bench 3: the support of the rotor that spins inside the body of the valve is prepared and assembled here
    - Operations 4,6,7 and 9 feed 5 and run parallel to each other
- Bench 4: Ultrasonic welding of the body is done here
- Bench 6: the core is assembled at this point
- Bench 7: U bracket assembly and preparation is performed
- Bench 9: polarity megging is performed (1.5% of the sub standard products from this process are directly drained)
- Bench 5: solenoid cutting, measuring, cleaning, flaming and re-cleaning are all done here
- Bench 8: solenoid setup and soldering completed here
- Bench 10: the units are potted in batches and sent on
    - Bench 11,14 and 18 feed process 19
- Bench 11: curing oven for the potted units
- Bench 12: lid drill, clean, cut groove oortjie and lastly clean
- Bench 13: lid bearing assembly
- Bench 14: lid diaphragm assembly
    - Processes 15 and 16 feed 18 and run parallel to one another
- Bench 15: rotor assembly
- Bench 16: plunger assembly
- Bench 18: plunger setup
    - Processes 11, 14 and 18 feed 19 and are independent of each other
- Bench 19: Valve closing and blowing inspection (defectives go back to process 8 then back to 19 once rectified)

- Bench 20: the nuts are torqued to close the valve assembly
- Bench 21: a pressure test is done on the valve with a success rate of 96.5% (failures go to 19 then through 20 again.

Electronic Assembly:

- Bench 29: the tag reader is prepared at this stage
- Bench 30: the tag reader is assembled
    - Note that processes 30 and 37 feed process 31
- Bench 34: pick up wire solder and magnet insert
- Bench 35: pick up reed switch solder and setup (2% failure goes to previous process, 34)
- Bench 36: pickup potting
- Bench 37: pickup cleaning and quality check (failure of 3.5% drained directly)
- Bench 31: electronic assembly
    - At bench 32 the mechanical valve from bench 21 joins up with the electronic component
- Bench 32: meter assembly
- Bench 33: RTE programming
- Bench 38: Test bench. Failure goes three directions depending on the type of failure: 5% valve failure (19,20,21,38) , 3% electronic failure (41,38) and lastly communication failure (29,30,41,38).
- Bench 39: functional test. Failures of 1.67% follow the following process route; 20, 19, 8, 19, 20 and back to 39
- Bench 40: antenna assembly
- Bench 41: cover assembly

42 and 43 are the final assembly stages:

- Bench 42: shipping; failures are 1% to 38 due to certificate (38,39,40,41), 1% to 29 due to faulty display (29,30,31,32,33,38,39,40,41), 1% to 31 due to MTS failure (31,32,33,38,39,40,41) and 1% to 40 due to cover (40,41). Each failure then runs through separate routes on the way back.

Mounting options:

- Bench 45: pipe cutting and chamfer and elbow
  - Process 45 and 48 feed the 49^{th} bench
- Bench 46: spindle prep, NRV prep and grease
- Bench 47: nut and NRV to manifold assembly
- Bench 48: press spindle into body
- Bench 49: manifold assembly
- Bench 50: pressure testing. 0.75% is due to the spindle therefore it returns to process 48 and another 0.75% I due to a leaky pipe and goes to process 49
- Bench 51: box assembly
  - The products of 42 and 51 feed the final process, 43, to produce the final product

Final assembly:

- Bench 43: final assembly

Table 8: description of the processes at each bench and the time taken per unit in seconds

Bench	Processes	Units/hr	Time/unit	Bench	Processes	Units/hr	Time/unit
1	Clean Burrs off spools	94	38.29787	29	N/P Pins & Wire Preparatio	44	81.81818
	Preparation	94	38.29787	30	Tag Reader Aseembly	38	94.73684
	Winding	38	94.73684	31	Pick-Up MTS	48	75
2	Body Drilling and cleaning	125	28.8	32	Meter Assembly & Battery	100	36
3	Rotor Support Prep & Assemb	125	28.8	33	Re-programming	63	57.14286
4	Ultrasonic Welding of Body	360	10	34	Soldering Wire & magnet	50	72
5	Cutting, Measure and Cleanir	75	48	35	Soldering reed switch & set	44	81.81818
	Cleaning&Flaming	75	48	36	Potting	125	28.8
6	Core Assembly	63	57.14286	37	Final QC testing & cleaning	125	28.8
7	U bracket Assembly and prep	125	28.8	38	Small TB	150	24
8	Solenoid Set-up & Soldering	59	61.01695		Large TB	450	8
9	Polarity - Megger	100	36	39	Functional Test	75	48
10	Potting	350	10.28571	40	Antenna Assembly	38	94.73684
11	Curing Oven	350	10.28571	41	Preparations (wires,cover,s	75	48
12	Drilling, blowing & deburring	125	28.8	42	Shipping Computer	94	38.29787
	Clean	125	28.8		User Token Ass	125	28.8
13	Bearing Assembly	125	28.8		Final (meter box) Ass	78	46.15385
14	Lid Assembly	125	28.8	45	Pipe preparation	71	50.70423
15	Rotor Flaming	163	22.08589	46	Spindle Cleaning Valve asse	71	50.70423
	Rotor Assembly	163	22.08589	47	Manifold Ass & cleaning & r	71	50.70423
	Testing	163	22.08589	48	Spindle to manifold	71	50.70423
16	Bending Levers	250	14.4	49	Manifold & pipe Ass	38	94.73684
	Paint Levers	250	14.4	50	Pressure Testing	56	64.28571
	Assemble Plunger Disc	188	19.14894	51	Box Drilling & cleaning	25	144
	Assemble Plunger & Lever	188	19.14894		Pipe , Elbow, level & Final A	38	94.73684
	Assemble Plunger Diaphragm	250	14.4				
	Silicon Tube/ Cut & Assemble	250	14.4				
18	Plunger set-up & check	81	44.44444				
19	Valve closing	44	81.81818				
	blowing	125	28.8				
20	Torque Range	125	28.8				
21	Pressure Testing (valve test)	81	44.44444				

Appendix F: Worker allocation and buffer information

Table 9: Indication of how many workers are allocated to each process and the time for each as well as the accumulated time

	resource	bench	time	total time		resource	bench	time	total time
1	person A				31	person EE			
2	person B	1			32	person FF	38		
3	person C		172.8	172.8	33	person GG			
4	person D	2	28.8		34	person HH		0.00	0
		3	28.8	57.6	35	person II	39	48	48
5	person E	4	10.00		36	person JJ			
		5	48.00	58	37	person KK	40 + 41	96	
6	person F	6	57.60	57.6	38	person LL		48	144
7	person G	7	28.80		39	person MM	42		113.28
		12.1	28.80	57.6	40	person NN		113.28	
8	person H	8	61.02	61.01695	41	person OO	45 + 46 + 47	50.70423	152.1127
9	person I	9	36.00		42	person PP		50.70423	
		10	10.29		43	person QQ		50.70423	
		11	10.29	56.57143	44	person RR	48 + 49 + 50		206.7532
10	person J	12.2	28.80		45	person SS		46.75325	
		12.3	28.80	57.6	46	person TT		96	
11	person K	13	28.80		47	person UU		64	
		14	28.80	57.6	48	person VV	51		240
12	person L				49	person WW			
13	person M	15 + 16	66.46		50	person XX			
14	person N		81.23	147.6923	51	person YY		240	
15	person O	18	44.31	44.30769					
16	person P	19							
17	person Q		55.54	55.54286					
18	person R	20 + 21	28.80						
19	person S		44.31	73.10769					
20	person T								
21	person U	29 + 30	82.29						
22	person V		82.29	164.5714					
23	person W								
24	person X	31 + 32	75.79						
25	person Y		36.00	111.7895					
26	person Z	33	57.60	57.6					
27	person AA								
28	person BB	34 + 35	72.00						
29	person CC		82.29	154.2857					
30	person DD	36 + 37	28.80						
			28.80	57.6					

Table 10: Buffer setup for the assembly line

Bench	Description	Buffer size	predecessors	successors
1	Coil winding	1500	-	Blinex (Ext)
15	Rotor assembly	250	-	18
16	Plunger assembly	250	-	18
21	Valve pressure test	250	20	32
36	Pickup potting	150	35	37
37	Pickup cleaning and QC testing	150	36	31
38 + 39	Test bench and functional testing	90	33	39

Appendix G: Full bench utilisation as a percentage in an 8 hour shift table

Table 11: Bench utilisation percentages

resource	working	setup	waiting	blocked	resource	working	setup	waiting
root.bench_16	100.00	0.00	0.00	0.00	root.phantom34	63.00	0.00	36.96
root.bench_21	100.00	0.00	0.00	0.00	root.bench_9	59.63	0.00	17.24
root.bench_15	100.00	0.00	0.00	0.00	root.bench_50	55.78	0.00	44.22
root.bench_1	100.00	0.00	0.00	0.00	root.phantom50	55.33	0.00	44.67
root.help1516	100.00	0.00	0.00	0.00	root.bench_37	52.80	0.00	0.46
root.bench_19	99.52	0.00	0.44	0.04	root.bench_122	50.00	0.00	50.00
root.bench_8	99.15	0.00	0.85	0.00	root.bench_121	50.00	0.00	12.23
root.bench_31	99.01	0.00	0.99	0.00	root.bench_123	50.00	0.00	50.00
root.bench_20	97.71	0.00	2.29	0.00	root.bench_14	49.90	0.00	50.10
root.bench_51	95.29	0.00	0.00	4.71	root.bench_13	49.90	0.00	50.10
root.bench_6	94.00	0.00	0.00	6.00	root.bench_2	47.10	0.00	47.10
root.bench_42	93.63	0.00	6.37	0.00	root.bench_3	47.10	0.00	0.00
root.bench_46	88.03	0.00	11.97	0.00	root.bench_7	47.00	0.00	12.35
root.bench_47	88.03	0.00	11.97	0.00	root.bench_32	46.94	0.00	53.06
root.bench_45	88.03	0.00	11.43	0.54	root.bench_41	42.50	0.00	57.50
root.bench_49	83.67	0.00	16.33	0.00	root.phantom41	41.78	0.00	58.22
root.phantom49	83.67	0.00	16.33	0.00	root.bench_48	40.75	0.00	59.25
root.bench_40	82.55	0.00	17.45	0.00	root.phantom48	40.75	0.00	59.25
root.phantom40	82.21	0.00	17.79	0.00	root.bench_10	16.69	0.00	83.31
root.bench_5	78.17	0.00	21.83	0.00	root.bench_11	16.69	0.00	83.31
root.bench_33	75.00	0.00	25.00	0.00	root.bench_4	16.32	0.00	83.68
root.bench_29	74.58	0.00	25.42	0.00	root.bench_38	3.19	0.00	96.81
root.bench_30	74.58	0.00	25.42	0.00	root.bench_39	1.67	0.00	98.33
root.phantom29	74.58	0.00	25.42	0.00	root.bench_36	0.90	0.00	99.10
root.phantom30	74.58	0.00	25.42	0.00				
root.bench_35	71.43	0.00	28.57	0.00				
root.phantom35	71.43	0.00	28.57	0.00				
root.bench_18	66.70	0.00	32.61	0.70				
root.bench_34	63.25	0.00	36.75	0.00				