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Simply Lean Simulations: bridging dynamic discrete-event simulation and Lean Six-Sigma process improvement techniques.

School of Industrial and Manufacturing Science

MRes Innovative Manufacturing – Engineering Management of Manufacturing Systems (option)

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**Simply Lean Simulations: bridging dynamic discrete-event simulation
and Lean Six-Sigma process improvement techniques.**

Supervisor: Dr. Benny Tjahjono

Academic Year 2004 to 2005

This thesis is submitted in partial fulfilment of the requirements
for the degree of MRes Innovative Manufacturing – Engineering
Management of Manufacturing Systems (option)

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Abstract

Techniques part of the Lean manufacturing philosophy have been widely adopted as a method of improving flow, while at the same time reducing waste within most type of business processes. The financially driven approach of the Six Sigma has not always combined easily with the flow-based principles within lean manufacturing philosophy, but the combination of these two techniques has been proven in the past to be possible with the evolution of the Lean Six Sigma philosophy. That approach can actually improve value to the customer as well as reduce the variation and waste within the critical processes of an organisation in order to deliver real financial benefits to the supply chain.

In the past lean practitioners have been wary to whatever had to do with the computer based simulations both due to the time that is needed to be spent in finalising the current and the future state maps and also due to the fact that lean practitioners seem to favour a more hands-on communication with the process itself, rather than a remote analysis like the simulation. Recognition of the “static” drag and drop value stream mapping software, gives an indication that lean practitioners are beginning to accept more the computer-based solutions in order to support collaboration and communication of value stream mapping.

BRM³ Ltd, the sponsoring company for this project, have developed a discovery learning simulation exercise called "Simply Lean", which is designed to take its participants from a basic to a full understanding of how to apply the most complex techniques which underpin Lean Six Sigma.

The purpose of the project is to investigate the extent to which a library of Lean Templates can be built in Simprocess, so that the enhancement of the learning experience as well as to demonstrate the validity of the simulation as a lean process improvement tool. The investigation in this project is covering the following tasks;

Firstly, the successful build of simulation models in Simprocess for each of the two key stages of the simulation exercise. The first model will replicate the Push processing technique used by many small companies the second a Mixed Pull system. Both the models were built with more successful to be the Push model, and the Mixed Pull to be partially incomplete. Secondly, the creation of a “Template Library” consisting of drag and drop V.S.M Icons in Simprocess, in order that simulations models can mimic the accepted appearance of a value stream maps. This was done in full very successfully and in conjunction with the previously mentioned simulation models, the third and last objective was achieved which is the evaluation of the effectiveness of Simprocess within a “Simply Lean” workshop, which was proved as successful since both the models are able to be used as training tools as well as an implementation aid within lean six sigma projects.

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1 Introduction

The need to maintain and improve competitiveness is a continuous challenge, which all manufacturing companies globally are facing. Competition is increasing in virtually every section of the market, which was assisted by the globalisation of the market. In order to increase the possibilities for survival, the companies have to make investments in new advanced technologies and reconfigure their existing facilities, which will help them cut down their costs, reduce the lead times for the delivery of their products to the customer as well as to improve the quality of their product and services. The introduction of these new technologies and changes in the system is something very difficult since every little mistake to the selection and orientation of these can be proven extremely costly for the company. Therefore there is the need to evaluate the benefits of these before their introduction. The easiest and the most efficient way to do this, is by simulation.

1.1 Overview of the Problem

Because all the above the need for change in the organisation is greater and more often than it used to be, this underpins the importance of the adequate training of the members of the organisation as well. That means the members of the organisation are also need to be trained sufficiently, whether because they have to make the change from one system, like from Push to the new system Mixed Pull, or whether they have to be trained so that they can operate correctly inside the new environment. This is something which BRM³ consultancy has understood and that they are addressing to their clients. Therefore a training package that will sufficiently educate as well as train their clients has to be created. Currently BRM³ uses the “Simply Lean” workshop for this purpose, but due to the fact that they believe that the introduction of computer simulation will be beneficial both to them, as a competitive edge against their competitors in the market, as well as to their clients since by simulation they will be able to see, participate and finally absorb more from the training workshop.

1.2 Overview of Research Aim

The aim of the project is the creation by the use of Simprocess simulation software the electronic form of the “Simply Lean” workshop, as well as its evaluation, firstly as a training tool, as well as an implementation aid within the Lean Six Sigma. In order for this to materialise, the researcher of this project has to use the simulation software provided by the sponsoring company in order to create two different simulation models that simulate the two stages of the workshop, Push and Mixed Pull. Furthermore, part of this development workshop is a Template Library which consists of twenty nine value stream mapping icons, which can be used in order to make the simulation models look more familiar to the participants who are more familiar in using the value stream mapping icons in the industry.

1.3 Overview of the Objectives and Deliverables

The objectives of the project are the following;

1. Build a simulation model for each of the 2 key stages of the simulation exercise within the Simply Lean Package, namely:
 - i) **The Batch Production System** (used by many small companies)
 - ii) **The Mixed Pull (Push-Pull) System**
2. Development a template in Simprocess for the above systems that can be easily re-applied within real life scenarios. This includes creation of a library of “Lean Icons” so that simulation models mimic the accepted appearance of a value stream map.
3. Evaluate the effectiveness of simulation tool within the “Simply Lean” package, making recommendations and refinements in its use both as a training tool, distance-learning tool and implementation aid within Six Sigma projects.

The deliverables of the project is the creation of an electronic form of the “Simply Lean” workshop which will be self-sufficient in running complete with the two specified simulation models, excel spreadsheets which help the models to run, as well as the completed and ready to use V.S.M Icon Library. Also the completed evaluation of the electronic Simply Lean workshop from the company, Mr. Peter Rice and Mr. John Britton, as well as a simulation expert Mr. Steve Allen.

1.4 Overview of Thesis Structure

The procedure that was followed in order to successfully complete the objectives and finally the aim of the project was a deep investigation in the currently used form of the “Simply Lean” workshop, which will identify the rules and roles in the system. Furthermore, it will assist the researcher to focus in all the most important elements of the workshop that accurately need to be replicated to the software simulation models. All the previously mentioned facts are represented in Chapter 2 of the thesis along with the brief overview of the sponsoring company. Also the identification of the advantages as well as the limitations of the workshop so that the researcher will be able to appreciate in a great extent the need for the use of the simulation.

In addition the extensive research in the literature, Chapter 3 of the report, for physical simulation as well as the software simulation will assist the researcher in identifying the limitation if any, in the knowledge of this topic in the industry. This will allow the

researcher to use the information currently available or ideas for the continuation of the project wherever there is a gap in knowledge that can be covered.

In Chapter 4 the development of the research aim and method is presented of the method that will be followed for the construction of the actual push and mixed pull models which, is the biggest part of this project, especially due to the fact that there were many problems to be overcome throughout the duration of the project. Very little training was received by the researcher, resulting in the completion of the mixed pull model very difficult to achieve. Moreover, the research for the available V.S.M icons available as well as their creation in Microsoft Visio Painter, and finally the creation of the V.S.M Library is also presented in Chapter 4.

In Chapter 5, the actual construction of these two models as well as every explanation of expression language used. In Chapter 5 many figures are used in order to achieve that since the nature of the material covered in that chapter is very difficult to explain without figures. Moreover, all the three steps that were followed in order in order for the objective to materialise are explained in great depth in this particular chapter.

Chapter 6 discusses the evaluation of the library templates that were used as well as their effectiveness combined with the two models. The evaluation is done from the sponsoring company and the feedback is collected from the researcher by conducting interviews with the interested parties as well as simulation expert.

In Chapter 7 the discussion of the findings and the overall assessment of the project as well as the researcher that completed are done. As a conclusion the sponsoring company, judged the completed project as highly successful despite the partially completion of the mixed pull model. The cooperation of both the sponsors and the researcher has been very good throughout the project something that gives an extra outcome of a more professional attitude to the project.

2 Industrial Context

In this chapter the researcher will try to break down the given “Simply Lean” workshop into its elements and this way to understand it better. The profile of the company that sponsors the project will be first in the list, and also the reasons that they use simulation as part of their Simply Lean workshop. The description of the scenario that the workshop is based on will follow as well as the roles and the rules that they have to be followed from the participants to this workshop. After this breakdown of the workshop is completed the advantages and disadvantages of the workshop and mainly of the simulation models will be identified.

2.1 The Sponsoring Company

BRM³ which is the sponsoring company of this project is a simulation software and consultancy business specialising in the field of the simulation modelling, risk assessment and management. They provide software & services for the modelling of business processes and they use simulation modelling in their effort to analyse and expand their client’s organisation knowledge of its risks, threats and opportunities. They help their clients to use business process modelling and simulation to evaluate the impact of change – without having the risks associated with the actual change. By doing so they ensure that the client organisation effectively tests before they invest and also ensuring that the right simulation methods and tools are used.

BRM³ provides experienced professional consultancy for the development and implementation of simulation analyses in areas such as:

- Risk and Asset Management
- Investment & Financial Modelling
- Business Process Re-engineering
- Availability, Reliability and Maintainability
- Supply Chain Management
- Six Sigma Programmes
- Strategic Corporate Planning
- Project Planning & Resource Management
- Team Building & Training Assignments
- International Logistics

Another major element of the work field of BRM³ is the offer of training in:

- Simulation studies
- Use of simulation software
- Statistics
- Data capture and analysis

As it is obvious from the above information the field that this project is concerned with is the part of the simulation training that BRM³ provides to their clients. Part of this simulation training that they provide is the “Simply Lean” package that they have developed and which is under examination from the researcher of this project.

2.2 Reason for Using Simulation

As mentioned before the use of the “Simple Lean” workshop, except the theoretical training that they provide to the participants, it requires them to take part to a “Lean Game” which will allow them to make practice everything that they learned in the theoretical part of the workshop. By doing so BRM³ can assess both the understanding of the participants in the workshop as well as their competence in whatever has to do with the lean principles.

The method that is currently used for assessing these is a physical simulation model, and this is the model that they want to convert into a computer simulation one. They believe that by using computer simulation models to run their experiments as well as to illustrate the physical changes to the shop-floor of an organisation it will give them the opportunity to intensify their training and understand more their participants’ needs as well as give them the competitive edge against their competitors.

2.3 Description of the scenario of the “Simply Lean” Workshop

In this section of the report the explanation of what is happening in the “Simply Lean” workshops is detailed. Also it is explained how the physical simulation is orchestrated as well as, the roles that each participant has to take into the game and the overall outcomes of the package.

2.3.1 The “Simply Lean” Workshop Explained

Before the further investigation for the Simply Lean workshop can start it is essential to quote what is believed by BRM³ that; *“Simply Lean is a training tool to assist companies to gain the benefits of the introduction of Lean Manufacturing and 6 Sigma techniques using their own employees to design and implement improvement programs.”* BRM³ “Simply Lean” workshop handout.

As it can be seen this is a workshop developed and run from BRM³, which is aiming in introducing the various elements of Lean Manufacturing in order to achieve business improvement as well as continuous improvement. The workshop is focused on:

- *Improving delivery performance*
- *Reducing excess transportation costs*
- *Improved productivity*
- *Improved Quality*
- *Reduction in Inventory*

- *Improved communication between Management and Staff*
- *Strategic Business Planning using electronic simulation*

The way that the workshop works is in the first stage creating a working model of a company which produces technical instruction brochures in a binder form. The company name is Binders International and is operating under a batch production system and the ultimate objective of the workshop is to enable the participants to discover how it can be re-engineered so that it operates using a Lean Manufacturing approach, as well as understand the beneficial effects that Lean Manufacturing principles have to the company.

The company, Binders International, currently employs approximately 60 workers in total, and in the past suffered cash flow difficulties caused by poor in house quality and delivery performance. The market receives the final product quite positively with only concern on the product's price. Another concern arises for the delivery performance of the company for which the customers are complaining and if this is sorted they will be very loyal to the company and the product.

The tasks that the company is planning to take are very specific and they are focused in resolving the problems analysed previously and these are summarised into the next three ones:

1. significant improvement of the delivery performance >98%
2. reduction of the cost of scrap and rework and optimisation of the inventory and raw material
3. increase of its flexibility response to the markets trends by minimising the lead times and product option flexibility

These three main objectives of the workshop are achieved by three sessions/workshops which are focused

1. on the company's family of A5 2 hole presentation brochures
 - Simply Lean Assembly
 - Simply Lean Process
 - Simply Lean Organisation
2. full implementation of Lean Manufacturing
 - participants perform 4 cycles where after each cycle performance measurements are taken, and adjustments are made to achieve improvements
3. progress meeting held so that to discuss the performance results and compare them with the three objectives set in the beginning

2.3.2 The Physical Simulation Model Currently Used

The model that BRM³ is using to illustrate the company's current situation, as well as to run the experimentation and implement the changes, consists from the following elements:

1. The raw materials, binders, A4 White Paper, A4 Coloured Paper and the Lamination Pouches, which are supplied from outside suppliers, are entering the systems to *The Paper Stores*, which is the department where they are kept until they requested to enter the production. This is the department that issues the materials to Assembly and Print Departments.
2. From the Stores Department the raw material are coming here, *The Print Department*, where the raw material is printed to the appropriate way. Here is the place where the Covers and the Spines are printed onto the White and Coloured A4 Papers as indicated below:
Prints Covers and Spines from A4 white Paper
 - Covers are printed two per sheet
 - Spines are printed ten per sheetPrints Dividers from A4 Coloured Paper
 - Dividers are printed two per sheetFinally the printed sheets are delivered to the Print Stores
3. *The Print Stores* are the work in progress storage area which holds the printed covers, spines and dividers prior to the Fabrication process.
4. Here is the next step after the Print Stores , where the printed papers are trimmed and laminated as indicated below, this stage of the production is called *The Fabrication Department*, and the processes that are happening are the following:
Trims Covers into individual items
Laminates and trims spines into individual items
Trims and Punches Dividers into individual items
All products are delivered to the Print and General Stores
5. *The Print and General Stores* is the department of the process where all the work in progress, from the Fabrication department as well as the general issues is stored prior to the Assembly Department.
6. In *The Assembly Department* (3Stations), the following procedures are followed so that the product takes its final shape ready to go the Shipping and warehouse department.
1st Station: unpacks the binders from the boxes and removes any packaging plastic trim. The supplied spine and front cover are removed and set aside. The binder is then passed to the next operation.

2nd Station: inserts the front cover and spine into the binder and opens out the ring binder. The binder is then passed to the next operation.

3rd Station: tabs and inserts the binders in the correct order and orientation and closes the binder and places into a box.

7. *The Shipping and Warehouse Department*, the product is delivered here by the storekeeper, which is received by the quality controller and inspected; and finally packed and consolidated in the warehouse either for shipment or finished goods storage.

The human resources needed to run the model is detailed in the following Table 1: Employees assignments and summary of responsibilities:

Table 1: Employees assignments and summary of responsibilities

Employee	Responsibilities
Print Operator	Produces printed Covers, Spines and Dividers
Fabrication Operator	Trims Covers, Laminates and Trims Spines, Trims and Punches Dividers
Assembly Operator 1	Unpacks Binders and removes covers and spines
Assembly Operator 2	Inserts Binder Cover and Spine and check rings
Assembly Operator 3	Inserts Dividers Tabs and Packs
Inspector	Inspects finished Binders and patrol all operations
Storekeeper	Is responsible for material flows to from all processes
Financial Controller	Report on performance and stock take results
General Manager	Chair progress meetings, lead improvement activities
Production Controller	Operate MRP and Issue schedules and liaises with customer
Mentor	Acts as Customer and Salesman

[“Simply Lean” Workshop handout supplied from BRM3]

Following is Figure 1 which is the overview of the model with the detail of the departments as well as which activities of the manufacturing of the binders is happening in each one of the departments.

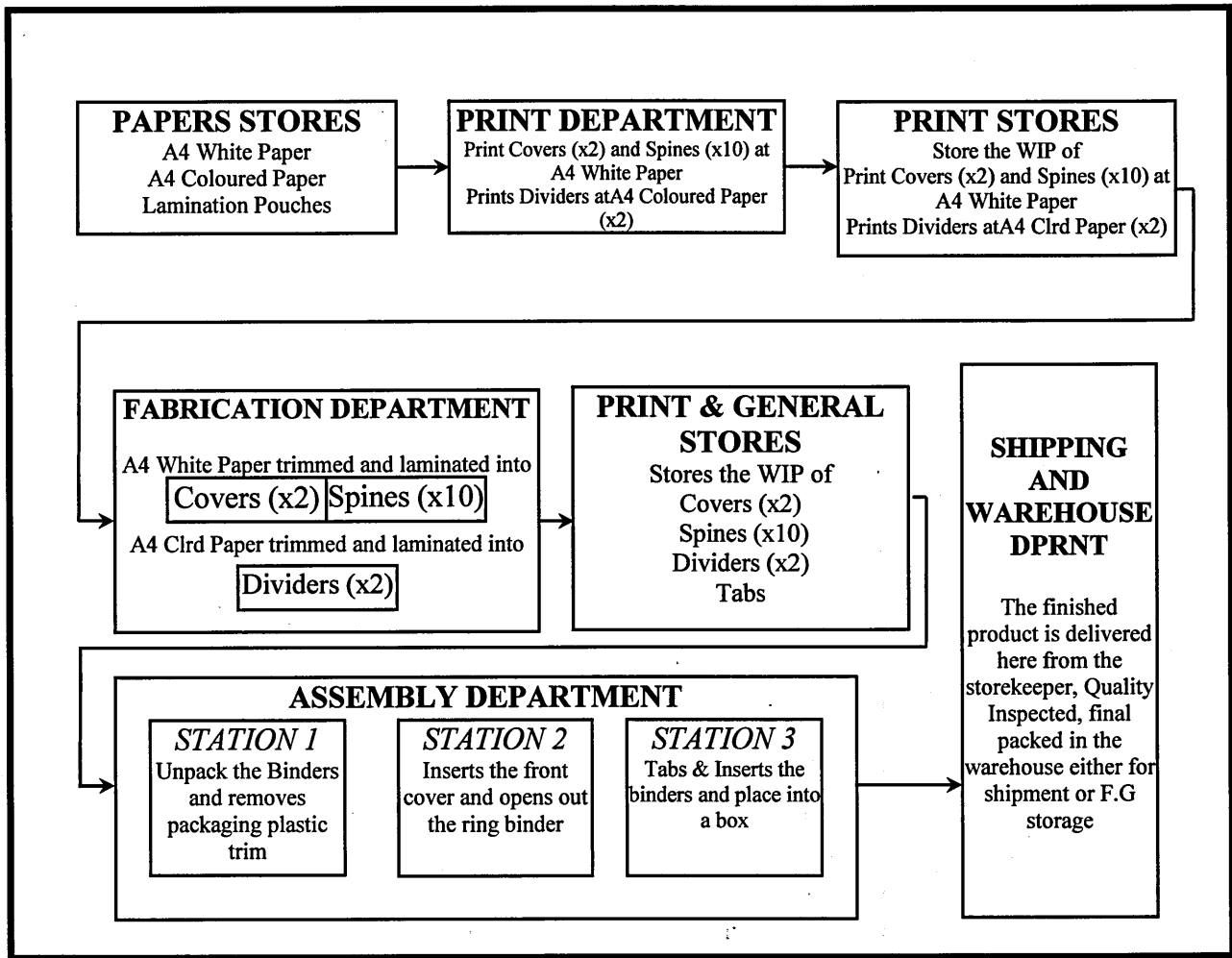


Figure 1: A Holistic View of the Current State Model used by BRM³

2.3.3 Learning Outcomes of the Simply Lean Workshop

By following these procedures of training simulating changes to the organisation the learning outcomes of the workshop that BRM³ is aiming to achieve are the following;

- Understanding of the Lean methodology, introducing concepts of Value, Value Stream, Flow, Pull and Perfection (customer empathy) and the process variation reduction tools offered in 6 Sigma.
- Life-like sequential, replenishment, mixed pull production and asynchronous flow, with high co-efficient of variance order intake characteristics with low inventory practices.
- The Workshops can be used to promote a company wide understanding of how to reorganise itself, into lean forms and the participants can be a horizontal,

vertical or mixed cross section of company employees involved in an open agenda cost reduction initiative.

- The ramifications of the Workshops and the reduction of non added value activities can be a cause of concern and the subjects of re-deployment and redundant activities must be discussed as part of the simulation, thus opening up the subject for clear debate.

2.4 Advantages and Disadvantages of “Simply Lean” Workshop

Having carefully examined the “Simply Lean” workshop and its scenario, the researcher wishes to state the advantages and the limitations that this program has, as an attempt to understand better the need for integration that BRM³ wishes to achieve.

2.4.1 Advantages of “Simply Lean”

The Simply Lean workshop by using a physical simulation model tries to represent the steps and stages of improvement activities in real life and gives an understanding of the methodology and approach, which can underpin a structured introduction into the company’s own workplace. By doing so they achieve to give a clear overview of the existing system of the organisation as well as make the participants aware of the limitations of the existing system.

Another strong point of the “Simply Lean” workshop is the ability that the participating organisation to revisit and replay the game, whenever each milestone in the company’s own continuous improvement roadmap is reached. By doing so the company is making sure that they keep their efforts on track as well as efficiently and quickly addressing any new problems, due to the changes, have occurred or surfaced.

Furthermore, the Simply Lean Organisation workshop is particularly tailored to address IT issues and accommodates the bridging between Lean Manufacturing, 6 Sigma and MRP / ERP approaches, which will act as a roadmap for the company and definitely benefit them.

2.4.2 The disadvantages of the “Simply Lean”

The Simply Lean Package that BRM³ is running although it is very well thought in its every detail in every aspect of the fictional company Binders International, it is remaining a workshop which is based on the traditional training models, which are used to teach and illustrate the effects of lean manufacturing. The logic behind it is based on workshops where the participants are taking part in a lean “game” which is aiming at teaching the participants the lean manufacturing techniques. By being based on the traditional models it still has the limitations that these models have.

The main disadvantages of the Simply Lean Package is the nature of the model that is used. The model by using the conventional hands on approach means that all the changes as well as the operations have to be done by the participants manually. This is very good for the participants to understand exactly of how the system is operating but on the other hand, this involvement has the drawback of the participant getting stuck with the detail and finally loosing the overall picture.

Furthermore, the time that the model needs to run is quite long and that is a limiting factor for both the run time and the number of experiments that can be simulated. As indicated in the Simply Lean booklet, the participants are taking place in only four simulation sessions, which as experimentation with a model is very small number. Implementing the changes that need to be done, it takes a lot of time since a simple change might involve the relocation of a workstation as well as the relocation of a human resource. These are taking a lot of time something that makes the total number of experiments shorter. Also because of the time that the operators need to do all the operations involved in one run of the model are quite a lot which again does not leave a lot of time for running the model for long periods due to the real time constraints. Also the complication that is involved in these models is such that after a while is almost impossible to run the model manually.

The time constrain that is involved by the use of the traditional models has another drawback to the participants. The lack of interest that is occurring during all this procedure is very common and makes participants to want to quickly finish with the experiments since it is dull for them to participate. The contribution that each participant is allocated to a specific workstation for each run makes them more uninterested since they cannot see what is happening to the rest of the model.

2.5 Summary

By summarising this chapter, it is important to say that the “Simply Lean” workshop has been fully analysed. That includes the analysis of all the elements of the workshop, including a very detailed profile of the facilitating company BRM³, as well as the reasons that they use physical simulation models, what they want to achieve by doing so as well as what this offer to the participants in the workshops. By doing so the researcher was able to clearly understand the importance of using simulation in their workshops. This is very important since the models that the researcher is called to create are going to be the replacement of this physical model, so it is very important to be able to replace it with a model that is equivalent if not more useful for the company.

Furthermore the analysis in the scenarios that the “Simply Lean” workshop is using is also very important since these are the information that will help the researcher to be able to understand the logic of the physical models as well as the rules that he has to follow in the creation of the computer based models. The roles as well as the workstations/departments of the models are broken down to the individual elements which allow the researcher to fully understand their individual importance as well as their interrelation as a system.

In addition the analysis of the learning outcomes as well as the advantages and the disadvantages that the workshop has is another way for the researcher to be able to evaluate the current model and the importance that this has in the workshop. This way the researcher will understand clearly the importance that the computer based models will replace the physical model during the workshop.

3 Literature Review

In this part of the report the benefits as well as the limitations of the simulation are explained as well as the practices that are currently used. By doing so the overview of the physical simulation is presented and the question “Why the need for new techniques?” is answered. Also the advantages and disadvantages of the computer simulation are listed and explained in large extend.

3.1 Overview of Simulation - Benefits and Limitations

“Simulation is a powerful tool for analysing, designing and operating complex systems. It enables you to test hypotheses without having to carry them out, saving you time and money, (http://www.imaginethtatinc.com/frame_simulation.html) which can only be beneficiary for an organisation.

Also the general advantages and disadvantages of the simulation are believed to be essential to be listed at this point of the research so as to be able to understand why simulation is used. The biggest advantage of the simulation is the ability that it gives to the user to ask the question “*What If?*” and actually test the “*ifs*” practically. By trying these “*What Ifs?*” it gives to the user a better understanding of the system as well as the interaction in this system by investigating the potential difficulties and making improvements.

The simulation of the existing facility as well as the adoption of the new elements in the system is very beneficial since the nature of the simulation gives the advantage to the user of having a very good overview of the system so that the mistakes are very easy to identify and the rectification of them is very fast and cost free.

The main disadvantage of the simulation is the ease of mistake making. The simulation model is as effective as its designer. If the designer is not consistent and do not use the correct logic for the model then the model is not going to provide any correct and usable results. The weakness of simulation is “*Rubbish In – Rubbish Out*” (Ball, 1996).

Furthermore, the results of the simulation are subject to the correct use by the investigator. The system does not gives a solution but instead it gives quantitative results, which means that their manipulation, as well as the correct understanding of the figures is a matter of the expertise of the user, something that is not always available.

3.2 Practices of Simulation

After having list the general advantages of simulation and state clearly what is meant by the word “simulation”, the research will continue by examining the different trends in the simulation. Firstly the physical simulation is explained as well as the limitations that this has.

3.2.1 Physical simulation

Before the Computer Simulation Software broadens its use to the simulation of processes and be treated as a training tool, the use of more hands-on approach, physical simulation, was the way of training as well as introducing changes in a manufacturing system. Before exploring in depth the attributes of the physical simulation the term of it has to be defined as expressed by *“As part of a holistic approach to creating and implementing a manufacturing system design, physical simulation is a tool that enables all stakeholders to interact with and to design a manufacturing system in a cost and time efficient manner”*, using the words of (Cochran, et al, 2000).

The creation as well as the implementation of a physical simulation in order to represent the real life system, involves ten lengthy and time consuming steps, which are listed below, the extensive detail of which is available in Appendix 1.

1. Current state VSM
2. Current state physical simulation design and current state VSM
3. Future state VSM
4. Future state physical simulation design and future state PM definition
5. Physical simulation demonstration of the current state
6. System design education
7. Evaluate current state and future state system designs with the MSDD
8. Integrate it infrastructure to support system objectives
9. Refine future state physical simulation with all team members
10. Develop standardise work

(Cochran, et al, 2000)

3.2.2 Physical Simulation Design and Implementation

The general guidance that must be followed so that a physical simulation for representing an actual manufacturing system must be followed is the following two ones:

Provide Detailed Working instructions for each operator as indicated by (Cochran, et al) *“It is critical to develop detailed instructions in order to define the work content in the simulation come from all levels within the manufacturing system.”* By doing so you can guarantee that all the participants to the process are familiar with the whole system, since they are coming from different sections of the same organisation. Also even if they are coming from the same sector that is simulated the simplification of the system so that it can be simulated has produces a different appearing system that they might not be able to correlate with it. These very clear work instructions will minimise this effect and will put everybody into gear with the system. *“Clear well-organised working instructions will enable the simulation to run smoothly, especially in the case when the participants are not familiar with the actual manufacturing system”*. (Cochran, et al, 2000)

“The physical simulation should be designed to reflect the material and information flow as defined by the current and future state value stream maps.” Although the physical layout does not need to reflect exactly the real life situation in the shop-floor, since limitations with the size of the production line can occur, and it is enough if the physical simulation represent the material flow as well as the information flow through the system rather than the size of it. *“The important point is that the physical simulation closely models the material and information flow relationships.”* (Cochran, et al, 2000)

3.3 Limitations of the traditional (Physical) lean training packages

The traditional Lean Training Packages have several disadvantages, compared to the same context lean training packages which are using computer simulation software in order to display and execute the experiments.

The way that the traditional packages tend to work is the comparison between the current state of a fictional organisation, and the future state of the same organisation so that to highlight the benefits those were obtained by the use of Lean Manufacturing techniques. In order those to occur, the participants of the training sessions have to make the changes to the current state system based on the lean techniques that they were taught. “Desktop models” or pen and paper models are mostly used in order to represent the current as well as the experimentation to the future state of the organisation.

The problems that occur with this tactic have to do with the lack of convincement of the participants of the training session since the whole process seems like a game and not as an actual learning session. At the same time this lack of realism from the “game” is something that makes them believe that the results that they have found are not very reliable and that in a way optimised to make the differences to stand out in favour of the future state. This is happening for several reasons based on the nature of the methods that they use. For example the changes in the system that they are making are not easy to spot since the changes between the current and future state are down to the detail that the creator of the model wants or have the time to do, which is something that makes them very subjective.

Also due to the nature of these traditional simulation methods, is such that the time that needs to be spend in order to amend the model, so that the changes can be introduced and make the improvements to the system, is quite big, which is adding up in the unpopularity and the non-effectiveness of the method. By having to deal with the time constraints of the traditional method, several other problems occur, that make them even less convincing for the participants of the workshop. One of them is the limited number of experiments that can be done so as to prove that the proposed solution has been the outcome of a thorough experimentation process as well as several stages of improvement and validation of the system and not just pure luck is which again is very difficult to do due to the time constraints.

Furthermore, the time constraint as well as the complexity of the desktop model is such that running an experiment for a long period of time, in order to simulate a year's or so production period, is impossible since many factors have to be considered every time the model changes. If this is added to the previous disadvantages of the traditional lean training packages, it is easy to see why the tendency is to adopt the use of simulation software packages in order to enhance these lean training packages.

3.4 Benefits of Computer Simulation

The use of simulation in conjunction with the traditional lean training packages is very beneficial since the outcome is very visual and is able to make the desired impact easier. The graphics that can be used in order to represent the current situation of an organisation as well as the future state of it are very strong to make the point. It is said "*A picture worth a thousand words*" Mayer and Gallini (1990), which explains the importance of why the use of computer simulation is vital. This is because the use of graphics enables the user to create a picture that make it easier to everybody to spot the differences between the current and the future state of the organisation and also and at the same time it is more convincing since the user is able to show the participants the changes, which was not possible to be done with the use of desktop simulation or just words. Mayer and Gallini (1990)

The time needed to introduce these changes to the system is much less and the quality of the changes is much better since the time constraints mentioned in the traditional packages does not exist, "*results can not just improve the quality of solutions, but do so in a relatively short time frame*" by McDonald et al (2002). The way that the model is constructed with the use of software simulation is very interactive, combining this with the data input that needs to be done in the model so that every operation functions as in the real life, aids the understanding of the system better and in much more detail. Also by doing so the participants are in a position to understand the interactions that every element of the system that they are studying has with the others. This is very important since the better understanding of the system the more efficient the system is to organise it and control it.

Furthermore, the elimination of the time constraints by the use of computer simulation, the run time of the model is such that allows the participant to run very long time models which can simulate run times of years in a relatively short time period. This enables the participant not only to see the short term effects that the changes have to the system but also the long term ones that most of the times are more important since this proves that the system that is implemented is going to withstand the changes in demand throughout the years. In addition, the simulation helps the identification of problems that will occur in the future and rectify them before these happen. Also by being able to run large amounts of experiments it assists the participant to evaluate the proposed solutions before these being implemented and by doing so choose the appropriate one for the system under study, before any large sums of money are actually spend on them.

The visual impact that the model has to the participants is much greater than the paper model or just words will ever have, since it represents the system much clearer and better. The changes can be seen which is very important, as it gives the feeling to the participant of actually doing the changes and not only planning them. The software always gives feedback from the changes that have been done by getting the results really fast which makes the participant to understand whether they are good or not. The actual movement of the product in the model from one operation to the other makes the participants not only visualising the processes but also seeing them happening in front of them.

“The greatest strength of simulation, however, lies in its ability to accurately reflect the randomness that we see in the real world”. (Hauge & Paige, 2002) This is very important when the represented system does not operate under constant demand. This is very common to most of the real life systems in every industry, since the customer demand is what a system has to meet. The limitation of the “paper and pencil” model, the models that are drawn on paper, is that by trying to represent the randomness in a system, the model becomes very complex and it is not possible to continue simulate by humans. Also this ability of the computer simulation to operate with this randomness in a system, *“allows us to better understand how a system will function under a variety of scenarios”* (Hauge & Paige, 2002) which is vital so that to set the system in such a way so that to be able to cope with these variations in demand, arrival rate and so on. The systems that do not need to work with randomness are very little, when the majority has to cope with randomness every day.

Before the further investigation of the benefits of computer simulation is detailed it is vital in this point to determine what Discrete Event Simulation is; *“In discrete-event models, discrete entities change state as events occur in the simulation. Orders arriving, parts being assembled, and customers calling are examples of discrete events. The state of the model only changes when these events occur; the mere passing of time has no direct effect.”* (Ball, P., 1996).

Having defined what is the discrete event simulation, it is essential to see why its use is beneficial for the teaching of lean manufacturing; *“Discrete Event Simulation has been shown to be a tool that can help to quantify the benefits of lean manufacturing...can provide creditable estimates of the savings in shop floor resources and the improvements in time-based performance statistics”* (Detty & Yingling, 2000). By using discrete event simulation to implement Lean techniques in the system under studying, it enables the participants to see the claimed results immediately and not only to imagine them. This is very important since, when the Lean Manufacturing claims that the inventory levels are minimised and that the balance of the workstation is achieved, all these can be seen by just running the model and watching the measurements, graphs that exist in the model. The additional advantage that an organisation has by using simulation to run experiments is that, simulation gives them the opportunity to test their

ideas and validate them against their systems specific site circumstances as well as test them against the current system before they actually decide to implement them.

3.5 Disadvantages of Computer Simulation

While simulation brings a lot of advantages, it is in fact time consuming. Data used in simulation is time consuming and costly to obtain. *“In some cases the time available to conduct simulation is limited to conduct a reliable study”* (Carson II, J.,S., 2003). In some situations, the animation and other visual displays, combined with the time pressure present on all projects, *“may mislead decision makers into premature conclusions based on insufficient evidence”* (Habchi & Berchet 2003). Inexperienced or over enthusiastic simulation analysts may many times forget the original goals and project timelines because their over involvement in the model building. In addition, *“simulation tools use concepts that are too complex for potential users”* (Habchi & Berchet 2003).

3.6 Summary

So as a training tool the discrete event simulation is much more effective since the combination of the graphics as well as the real time changes and results, make it very powerful. The interactive nature of the simulation, makes the participants to hook on to it, and quarantines that it will keep their interest much more than a piece of paper and a pencil, or just a person speaking to them for the positive effects of Lean. By doing so it enables the participants to make practice the theory that they were taught and test their understanding on Lean Manufacturing, which will make them believe in the new system and make them more committed to the changes.

Although the software simulation has many advantages there are some important disadvantages that have to do more with the way that is used. The user need to be much focused and clear in what he is trying to achieve and not to get carried away with the extreme detail and animation. The training is another issue that needs to be addressed as well as the sufficient time to gather the information needed to build correctly the model.

4 Development of the Research Aim & Method

In this section of the report the aim and objectives of the research are going to be clarified. The framework that these are going to be achieved is also to be carefully explained stage after stage something that will help to establish a detailed method on which the project has to stick so that to be successful.

4.1 Aim, Objectives and Scope

Before the detailing of the objectives can start it is vital at this point to make clear what the purpose of this research is. Discrete Event Simulation is the medium that is going to be used in order to improve the existing training package for Lean Manufacturing, the “Simply Lean”, which BRM3 currently very successfully run. The desired outcome of this project is the creation of an electronic form of this training package, named the Electronic “Simply Lean” workshop.

In order to do so, two specific models, Push, and Mixed Pull, have to be build which will assist in doing so. The aim of this project is the development of a Template in Simprocess for the developed models, which will allow the easy real life application to new scenarios, by creating a library of Lean Icons. Furthermore, the evaluation of the effectiveness of this simulation tool that has been developed is going to be assessed;

- i. as a training tool
- ii. as a implementation aid within lean six sigma

In order all these to materialise clear objectives have to be identified, which will assist to the better and more effective analysis and ultimately solve of this issue. The following three objectives are believed to be the key ones for the development of the research.

1. Build a simulation model for each of the 2 key stages of the simulation exercise within the Simply Lean Package, namely:
 - i) **The Batch Production System** (used by many small companies)
 - ii) **The Mixed Pull (Push-Pull) System**
2. Develop a template in Simprocess for the above systems that can be easily re-applied within real life scenarios. This includes creation of a library of “Lean Icons” so that simulation models mimic the accepted appearance of a value stream map.

3. Evaluate the effectiveness of simulation tool within the “Simply Lean” package, making recommendations and refinements in its use both as a training tool, distance-learning tool and implementation aid within Six Sigma projects.

4.2 Programme & Deliverables

Now that the aim and objectives have been clearly identified and stated the development of the correct method that the research will take place has to be detailed. The method consists of four clearly defined stages, and each one of them clearly states the actions to be taken as well as the purpose and the deliverables of each one of them. The degree of this detailed has been judged as essential in order the successful meet of the aims and objectives to be guaranteed.

4.2.1 Stage 1 – Development of the Electronic “Simply Lean” Workshop

Step 1 - Build the Push model - Evaluation of the Model

The purpose of this stage is to set the correct foundations upon which the project will be built. It is very important to set the correct base for the project in this early stage since that will guarantee the worthiness of the findings. As an objective of this stage is the creation of the two main models, Push and Mixed Pull, so that to be able to simulate the exact situation that the sponsoring company wants to achieve. It is very important that the models correspond to the real life scenario since with this way the models will be usable and valuable to the company as a more effective training tool than the current one.

In order to achieve this objective the work will have to be divided into small portion so that they will be easy to follow and to trace it back. So the steps that will be followed are the following;

Firstly, the clear understanding of the simulation software that the sponsoring company wishes to use, must be obtained, which means that the researcher of this project have to spend a certain amount of time in the effort to familiarise with it. Also the fact that the researcher of this report does not have previous experience into using the specific software needs to be addressed. Except the software, a very clear picture for the Simply Lean scenario that is used form the BRM³ is vital since that will guarantee, that what is simulated in the computer software, corresponds exactly to the current physical model.

The familiarisation with the model as well as the computer software will take some time, but it is something that needs to be done. After this period of familiarisation has been completed the next stage is to start building the actual model. First the Push and

then the Mixed Pull, which again is going to be time consuming since the only aid available to the researcher is the user manual that has been supplied with the software.

Then after the completion of the two models the next step is to proceed with the evaluation of the models against the expectations of the company. That needs to be done since the final user of the models is going to be BRM³. Also the exact timings for each one operation or other element of the physical model have to be input in the models so that it becomes exact replica of the physical model. Having evaluated the models from the company the next stage is to gather their feedback and readjust the models to suit their expectations.

The procedure of getting the feedback and readjusting the models has to be repeated many times so that the models will correspond to both the expectations as well as the currently used models.

Step 2 - Build the Mixed-Pull model - Evaluation of the Model

After the completion of building and verifying the models against company's expectations as well as compliance with the rules of the "Simply Lean" workshop the proceeding into building the Mixed Pull model has to be done. The careful consideration of the different rules that this model has due to the different nature, is another element of this work. Also the understanding of the rules as well as exactly of what the model is trying to prove has to be clearly identified. After this introductory period ends the building of the actual model may start, by following similar procedures to the stage 1- push model.

By completing the building of the models the deliverables to the sponsoring company will be the finalised Push and Mixed-Pull models. That is a milestone for the progress of the project and that will allow the researcher to readjust the timetable for the project.

Step 3 - Development of a template in Simprocess

The third stage of the project will be the development of a template for the above systems that can be easily re-applied within real life scenarios. This will have to include creation of a library of "Lean Icons" so that simulation models mimic the accepted appearance of a value stream map. Also the introduction of the icon library to the model so that the model use these templates to build the simulation models and make it easier for the final user to understand the lean techniques and the effects of them.

In order for the above stage to be completed successfully the researcher has to follow the steps that are following:

Firstly the need for research in the field of the Value Stream Mapping for two reasons, one because of the familiarisation of the researcher with the symbols and their meaning as well as the identification of all the available symbols so that the template library will be complete.

Secondly the researcher has to spend enough time into replicating these symbols in appropriate software so that these can be imported in the Simprocess interface. The selected software for this occasion will be the “Microsoft Visio Drawing 2003 version” and this is due to the fact of the easiness of use of this specific software. After the icons have been created with the aid of Microsoft Visio Drawing, it will be time to convert them into JPEG files so that they are easy to import into the Simprocess interface and see if they function as appropriate. After this stage has been completed and the icons are functioning as expected they will be presented to the sponsoring company and ask for feedback. Some changes might be needed to the designs and so on some time must be allocated for that as well. After this procedure has been completed the deliverable of this section of the research will be the completed Icon Library ready to be used from the sponsoring company.

4.2.2 Stage 2 – Evaluate the Effectiveness of the Templates & Models within the Company

The final stage for this project is the gathering of the feedback from the company that will allow the researcher to evaluate the quality of his work as well as the quality and the functionality of the models that he has delivered to the sponsoring company.

The method that is going to be used for this stage is the interview, and it is vital for the researcher to research the interview techniques so that to be able to gather the correct feedback that will highlight any problems with the completion of the project. The analysis of the feedback gathered from the interview will be the most important stage, since this will allow the researcher to reflect at his work and make corrections as well as draw conclusions and recommendations for future work.

5 Stage 1 - Construction and Evaluation of the Models

Having detailed the disadvantages of the physical simulation in the previous section of this report, the recreation of the Simply Lean game by the aid of simulation software at this point is vital. The aim of the researcher of this project is to recreate the two basic models currently used in the workshop, Push System, and Mixed Pull, in order for the facilitators to be able to use it in their workshops.

The two models are very different in their layout as well as their configuration which makes them suitable for their use in order to simulate variance in the production system. In this section of the report the explanation of how the models were built as well as the significant elements that make the difference between them is presented.

5.1 Step 1 - Building the Push Model

Following at this section of this project is the method that the model has been constructed as well as the actual model explained with figures.

5.1.1 Methodology of Push Model

The Push model has an overall logic stated from the “Simply Lean” physical model that needs to be followed, Figure 2, shows the logic behind it;

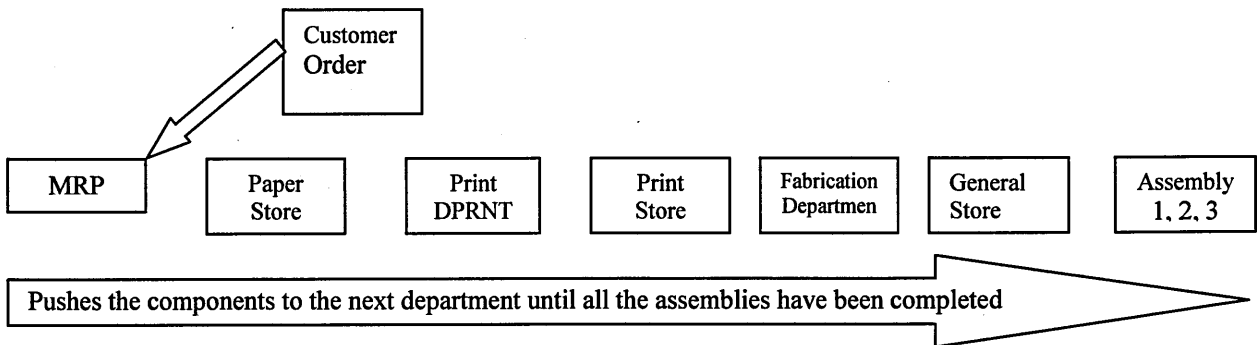


Figure 2: Overall logic that has to be followed for Push Model

In order to make the model to function as appropriate the correct code has to be set in the interface of the model. This will guarantee that the correct amount of raw material will be entered to the system as well as that the correct amount of products will be generated.

In order to do so an excel spreadsheet had to be created, to drive the generation. The formulation of this excel spreadsheet is vital so that it acts as Bill of Materials and it transforms an order of Finished Products into individual numbers of smaller components that all together form the Final Product. An example of a Bill of Material

that has to be followed in order to correctly formulate the excel spreadsheet is shown in Figure 3;

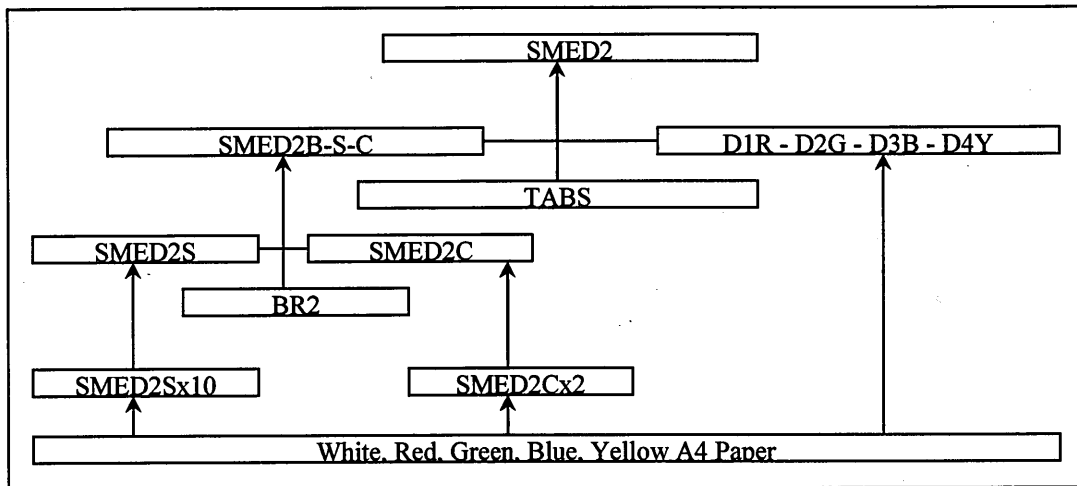


Figure 3: Bill of Materials of SMED2 final Product

As it can be seen in Figure 3 the Bill of Materials of the end product SMED2 which, as it can be seen clearly, is broken down into its individual modules. There are fourteen different elements which are coming together in different times during the manufacturing procedure. So by following this bill of material and doing so for all the seven different end products the researcher was able to formulate the excel spreadsheet and link the different elements together, which allowed him by just changing the quantity of the end products to get the exact breakdown of the quantity of the individual modules that are contained in the end product.

There is also a method that needs to be followed for the formulation of the excel spreadsheet. The fact that the following divider configuration had to be followed for the assembly of each binder is another obstacle that needs to be addressed. The 2 Hole Presentation Brochure comes in 3 Binders colours, Red, Blue and Black. The Binders have 4-tabbed segment dividers inserted into the binder in the following configurations.

Table 2: Divider Configuration

Part No	Binder	D1R	D2G	D2B	D3B	D3Y	D3O	D3G	D4Y	D4O	D4B
EXB2	BR2	1	1	0	1	0	0	0	1	0	0
MNB2	BB2	1	1	0	1	0	0	0	0	1	0
TTB2	BL2	1	1	0	0	1	0	0	0	1	0
SMED2	BR2	1	1	0	0	1	0	0	0	0	1
SPFB2	BB2	1	1	0	0	0	1	0	0	0	1
TPM2	BL2	1	1	0	0	0	1	0	1	0	0
QFDB2	BR2	1	0	1	0	0	0	1	1	0	0

There are also rules for the printing of the different papers that need to be followed;

Printing of Covers and Spines from A4 White Paper

- Covers are printed two per sheet.
- Spines are printed in ten per sheet.

Prints Dividers from A4 Coloured Paper

- Dividers are printed two per sheet.

This needs to be considered as well as the rest of the rules for the correct formulation of the excel spreadsheet.

By following all these rules the researcher of this project was able to construct linked spreadsheets in Microsoft Excel and that way to reassure that the correct amount of materials will enter the system.

After the construction of the spreadsheet was completed the next thing to be done was to set the model appropriately for reading this Excel spreadsheet. In order to achieve that, the following expression language had to be inputted in the generation block under the Start Simulation mode;

Note: Highlighted with blue is the expression language and in normal black text is the explanation wherever this is judged as essential.

```
IN : REAL;
```

This means that the inputted numbers are Real and not Integers

```
Model.INXL := OpenSpreadsheet("Input","C:\\INPUTSSS.xls");
```

This means that the model reads from the excel spreadsheet named INPUTSSS and that this is placed in the c drive of the computer.

```
ReadFromSpreadsheet(Model.INXL,"TESTSHEET",3,12,IN);
```

```
Model.WHITE := IN;
```

```
ReadFromSpreadsheet(Model.INXL,"TESTSHEET",4,12,IN);
```

```
Model.RED := IN;
```

```
ReadFromSpreadsheet(Model.INXL,"TESTSHEET",5,12,IN);
```

```
Model.GREEN := IN;
```

```
ReadFromSpreadsheet(Model.INXL,"TESTSHEET",6,12,IN);
```

```
Model.BLUE := IN;
```

```
ReadFromSpreadsheet(Model.INXL,"TESTSHEET",7,12,IN);
```

```
Model.ORANGE := IN;
```

```
ReadFromSpreadsheet(Model.INXL,"TESTSHEET",8,12,IN);
```

```

Model.YELLOW := IN;
ReadFromSpreadsheet(Model.INXL,"TESTSHEET",11,12,IN);
Model.BR2 := IN;
ReadFromSpreadsheet(Model.INXL,"TESTSHEET",12,12,IN);
Model.BB2 := IN;
ReadFromSpreadsheet(Model.INXL,"TESTSHEET",13,12,IN);
Model.BL2 := IN;
ReadFromSpreadsheet(Model.INXL,"TESTSHEET",16,12,IN);
Model.TABS := IN;
ReadFromSpreadsheet(Model.INXL,"TESTSHEET",17,12,IN);
Model.LAMINATOR := IN;
ReadFromSpreadsheet(Model.INXL,"TESTSHEET",3,3,IN);
Model.EXB2N := IN;
ReadFromSpreadsheet(Model.INXL,"TESTSHEET",14,3,IN);
Model.MNB2N := IN;
ReadFromSpreadsheet(Model.INXL,"TESTSHEET",25,3,IN);
Model.TTB2N := IN;
ReadFromSpreadsheet(Model.INXL,"TESTSHEET",36,3,IN);
Model.SMEDB2N := IN;
ReadFromSpreadsheet(Model.INXL,"TESTSHEET",47,3,IN);
Model.SPFB2N := IN;
ReadFromSpreadsheet(Model.INXL,"TESTSHEET",58,3,IN);
Model.TPMB2N := IN;
ReadFromSpreadsheet(Model.INXL,"TESTSHEET",68,3,IN);
Model.QFDB2N := IN;

```

These series of lines make sure that the model reads from specified spreadsheet and more specifically that it reads from the Sheet named "TESTSHEET" and the numbers that following are indicating the row and number respectively. As it can be seen there is always a line underneath the Read line which always is indicating to the system the name of the entity of the specified location.

This part of the expression language makes sure that the model will generate the correct amount by following the rule for the printing of covers and spines;

```

Model.SPINES := CEIL(Model.EXB2N/10.0) + CEIL(Model.MNB2N/10.0) +
CEIL(Model.TTB2N/10.0) + CEIL(Model.SMEDB2N/10.0) +
CEIL(Model.SPFB2N/10.0) + CEIL(Model.QFDB2N/10.0) +
CEIL(Model.TPMB2N/10.0);
Model.COVERS := CEIL(Model.EXB2N/2.0) + CEIL(Model.MNB2N/2.0) +
CEIL(Model.TTB2N/2.0) + CEIL(Model.SMEDB2N/2.0) +
CEIL(Model.SPFB2N/2.0) + CEIL(Model.QFDB2N/2.0) +
CEIL(Model.TPMB2N/2.0);

```

As it can be seen it takes every quantity of the end product and depending of whether it has to calculate Spines or Covers it divides it by 10 or 2 respectively and then rounds it up (CEIL) due to the fact that the system is not allowed to create a spine page which will print 5 spines for EXB2 and 5 for MNB2, but it has to create even if you need 1 spine for EXB2 a whole white paper printed with 10 EXB2's spines. When this procedure finishes then it adds up everything together to get the total number of White Sheets that it needs to generate.

In order to make sure that the correct amount of products are created and so on there isn't a case of generating random materials, the following code had to be inputted so that to make sure that it calculates them correctly. In the spreadsheet that was created there is an area that is similar to the Table 2 in page 32 and that is indicating to the system which binder has to create for which binder. For example the D1 position in the area in the Excel Spreadsheet "INPUTSSS" is the D1R divider, which needs to be generated as the sum of the End Products; EXB2 plus MNB2 plus TTB2 plus SMEDB2 plus SPFB2 plus QFDB2 and finally plus the TPMB2, and so on.

Model.D[1] := Model.EXB2N + Model.MNB2N + Model.TTB2N + Model.SMEDB2N
+ Model.SPFB2N + Model.QFDB2N + Model.TPMB2N;

Model.D[2] := Model.EXB2N + Model.MNB2N + Model.TTB2N + Model.SMEDB2N
+ Model.SPFB2N + Model.TPMB2N;

Model.D[3] := Model.QFDB2N;

Model.D[4] := Model.EXB2N + Model.MNB2N;

Model.D[5] := Model.TTB2N + Model.SMEDB2N;

Model.D[6] := Model.SPFB2N + Model.TPMB2N;

Model.D[7] := Model.QFDB2N;

Model.D[8] := Model.EXB2N + Model.QFDB2N + Model.TPMB2N;

Model.D[9] := Model.MNB2N + Model.TTB2N;

Model.D[10] := Model.SMEDB2N + Model.SPFB2N;

Whenever there is a branch that has to deliver the entities into for example two different process blocks then there are several ways to do it as it can be seen in Figure 4 that follows;

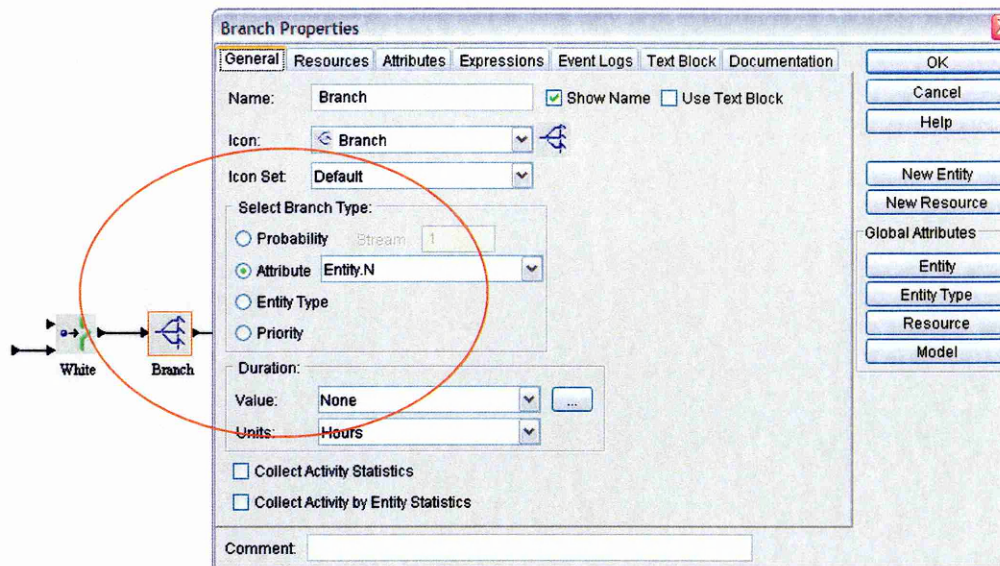


Figure 4: Inside a branch in order to select how the distribution to the braches will happen

Depending from the place into the process that you are, you can select whether it is going to be “by simple probability”, expressed into percentages (0.20 = 20%), or “Attribute type”, “Entity type” or finally “Priority”. In our case the selected one as it can be seen is by entity due to the fact that our running time is not such that allow us to do it by probability, and our position in the manufacturing procedure is such that does not allow us to do it by Entity type since at this point is simply a white paper that needs to be distributed to the branches and then converted into different entities. As it can be seen from Figure 4 there is an entity type N which is allowing us by using the following expression language to distribute them into the desired quantities.

Under the Release Entities Mode of the Expression Properties of the Branch the following code is imported;

```
IF Model.SPINES > a
Entity.N := 1;
a := a + 1;
ELSIF Model.COVERS > b
Entity.N := 2;
b := b + 1;
ENDIF;
```

This code says that: If the Model Spines that the system has read from the excel spread sheet is greater than a where a =a+1 then Entity N = 1, otherwise (ELSEIF) the Model Covers greater than b which b =b+1 and Entity N= 2.

Now in order for this to work correctly the next step is required as shown in Figure 5

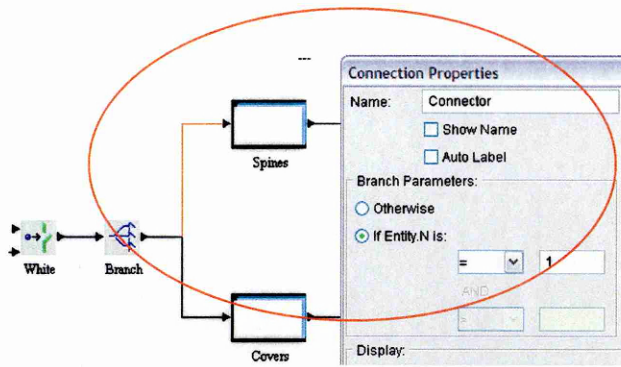


Figure 5: Inside view of the properties of a connector

As it can be seen circled with the red circle, the connector's properties have been set into accepting the Entity N if it is equal to 1 which corresponds to Spines. In this way it is made sure that the materials are delivered to the processes in the correct amount as specified. In the case of the covers the Entity N equals to 2 and if we have more than two then we need to increase the number up to the desired one.

Another example from the same model in a different placed branch shows the significant difference between how to set up a branch to split entities. Figure 6 shows the splitting by Entity Type after we have converted the white paper into individually named depending from the route that has to follow in the system;

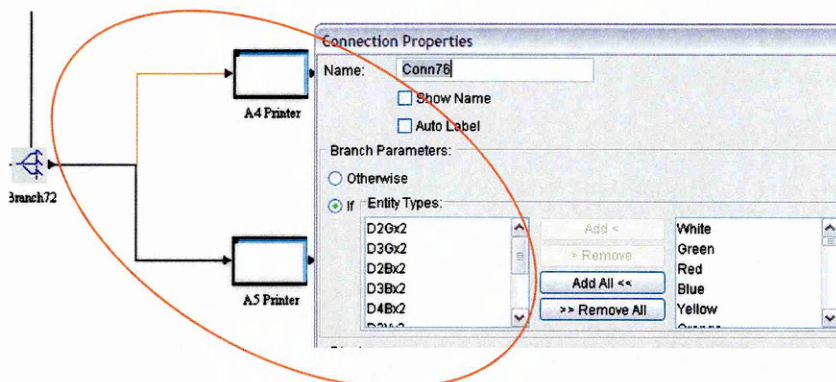


Figure 6: Branch set up for accepting by entity type before the components enter the printers

In this case by simple inputting the name of the entity to the connector it will accept only the incoming entities with the specific name.

In order to be able to take some of the measurements from the system like throughput time it is vital to introduce an attribute to the system that will allow that to happen. The attribute name is T1, and it has to be copied in each one of the components that is passing through the system. To achieve this, the system has to be set in such a way that will allow the attribute T1, to be attached in every single component that passes through. This forced the researcher not to use the obvious solution of the "Assembly Blocks", since that will not allow the T1 to pass through since it will not be member of the assembly, but instead to use "Synchronisation Blocks" which are set in such a

manner that allow so. The examples in Figure 7 and Figure 8, that follows shows exactly that.

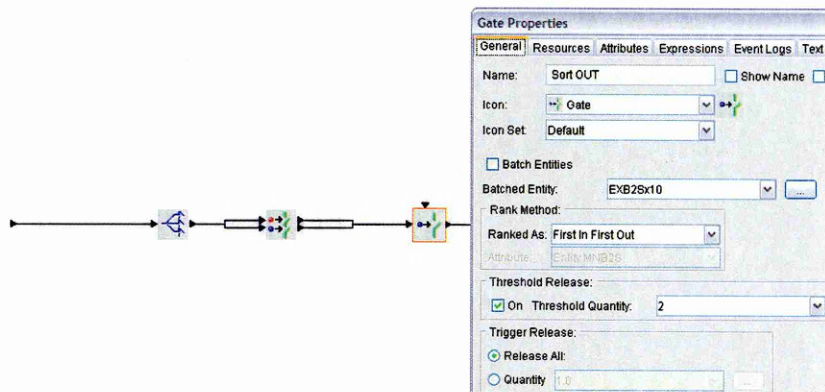


Figure 7: Set up of the gate in one of the assemblies to allow the entity to release the attribute T1

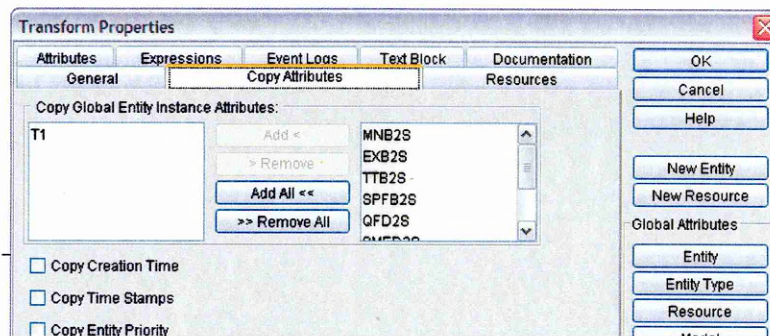


Figure 8: Set up of a transform block to allow the attribute T1 to be copied and carried out through the system

Also in order to materialise this, an extra expression language has to be used as well as the correct setting of the gate and synchronisation blocks. This is due to the importance that since the throughput time is important to be measured from the very beginning that one of the components of the end product entered the system as well as the latest one that exit the system. To achieve that the expression that was used is the following;

```
IF N =6
    N:= 0;
ENDIF;
```

```
N := N+1;
```

This line makes sure that combined with the setting of the gate block it will reset the counter.

```
Entity.N := N;
```


In this way the latest entity is finally released and measured from the system that is vital for the correct measurements to be taken.

Also in order to take this Throughput Time measurement the dispose box at the end of the model has to set correctly by using expression language.

“Dispose Block”

`Model.TPRODUCT := SimTime("Seconds") - Entity.T1;`

This is the expression language that is used in order to count in seconds the time that it took the last component to be attached in the end product and pass the whole of the system.

`OUTPUT("DIS ",Entity.Name);`

This expression language is the code that allows the programmer to verify that the correct amount of components is produced.

5.1.2 Model 1: Push Model

The push model was developed with the idea of using the traditional push technique, which means that the products are coming into the system and are pushed to the customer through the system. We do not take into consideration the customer demand at the moment, but we produce in such rate so that to meet the estimated demand that we have. The overview of the Push model is shown in Figure 9:

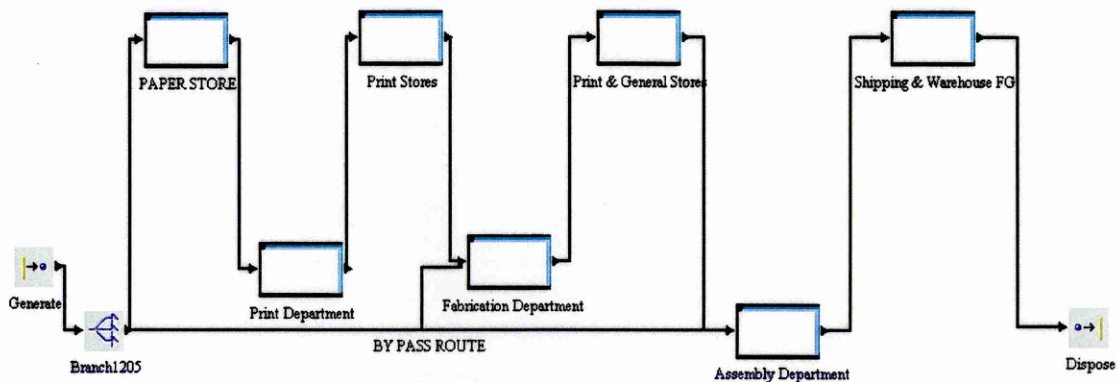


Figure 9: Overview of the Push Model

As it can be seen in Figure 9: Overview of the Push Model, the model replicates exactly the currently used push system, by the physical simulation which makes it very effective. All the departments that need to be used from the physical simulation are there. We start from the generate Icon which can be seen as the incoming materials to the system and that is controlled from the MRP system of the company. There are some elements in the system that needs to be taken under consideration. These were the fact

that some of the resources had to be placed in different stores than the paper store. The Tabs, Laminator pouches and Binders have to be placed in different points of the system. The laminator pouches have to be placed in the fabrication department since they are used in the Laminating process only, and only for the spines. So the use of a bypass lane was vital so they are carried all the way through the system. Also the Tabs and the three different kinds of Binders BR2, BB2 and BL2, had to be delivered in the assembly department so that they can be used in the workstation 3 and 1 respectively. Again due to this constraint the use of another by pass lane was crucial to be used.

In more detail Figure 10, represents the paper stores, as it can be seen each of the paper has it own position where it is transformed into the desired resource.

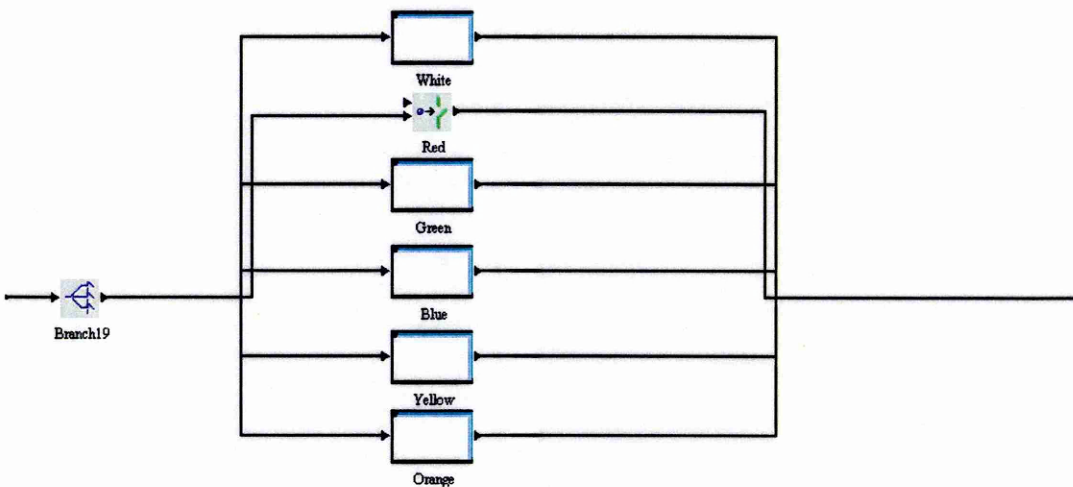


Figure 10: Differentiation between the various kinds and different kind of routings of the paper

The

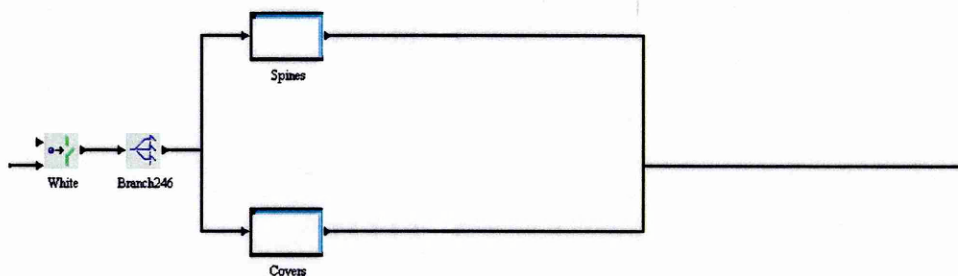


Figure 11: Differentiation of the white paper into spines and covers

white paper is more complicated to deal with since from a single kind of paper, two different kinds Spines and Covers. Both of these kinds have to be sorted into the different print outs so that to be placed in the seven different kind of the end products as shown in Figure 11

In Figure 12 is the further differentiation of the white paper into covers for the seven different final products is shown. It is essential to make the differentiation of the covers in this place since from this point onwards the model can treat these papers as different entities with individual routings in the system.

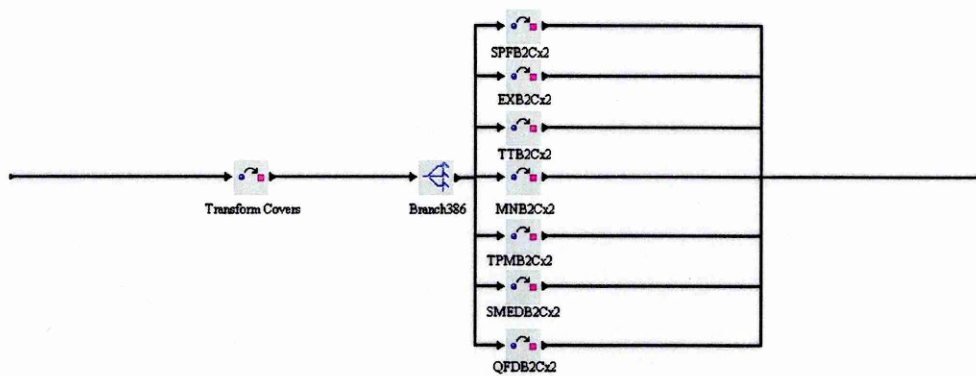


Figure 12: Differentiation of the white paper into different entities paper and routings in the system.

The same applies to the Spine process, with the same way, where a simple white paper was transformed into white paper spine and assigned to a specific final product, e.g. SMEDB2Sx10. In order for this to explain these codes, SMED instruction binder, allocated for Spine which will print 10 spines in one A4 paper. The same coding is followed for the rest of the papers.

The next stage is the stage of the Printing of the actual details on the papers; there are two main routes for the paper, the A4 Printer for the coloured printer and the A5 Printer for the White ones. In order for this to happen the use of a branch is necessary, and by routing them by entity type. Figure 13 shows exactly that:

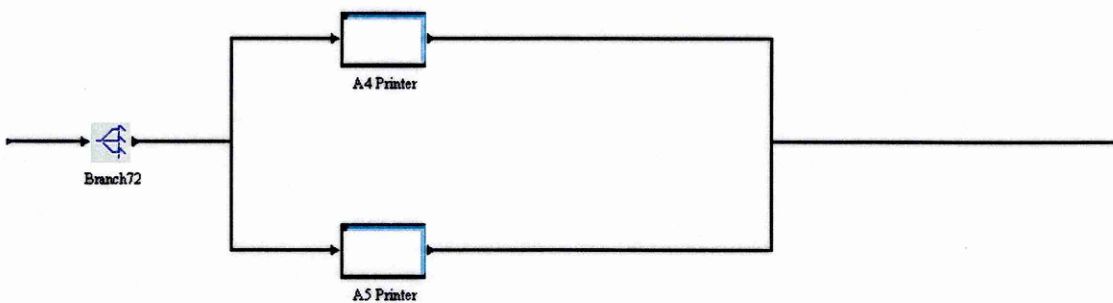


Figure 13: Differentiation of the routing between A4 and A5 Printer

After the paper is printed is ready to proceed to the next stage which is the stage of the fabrication. In this stage the paper covers, spines and dividers are separated and are becoming separate entities in the system. This is possible to happen by the use of a transform icon which is transforming the 1 entity of e.g. SMEDB2Sx10 into 10 separate SMEDB2S. In the following Figure 14 it is representing exactly this for the coloured papers; exactly the same procedure is followed for the white paper.

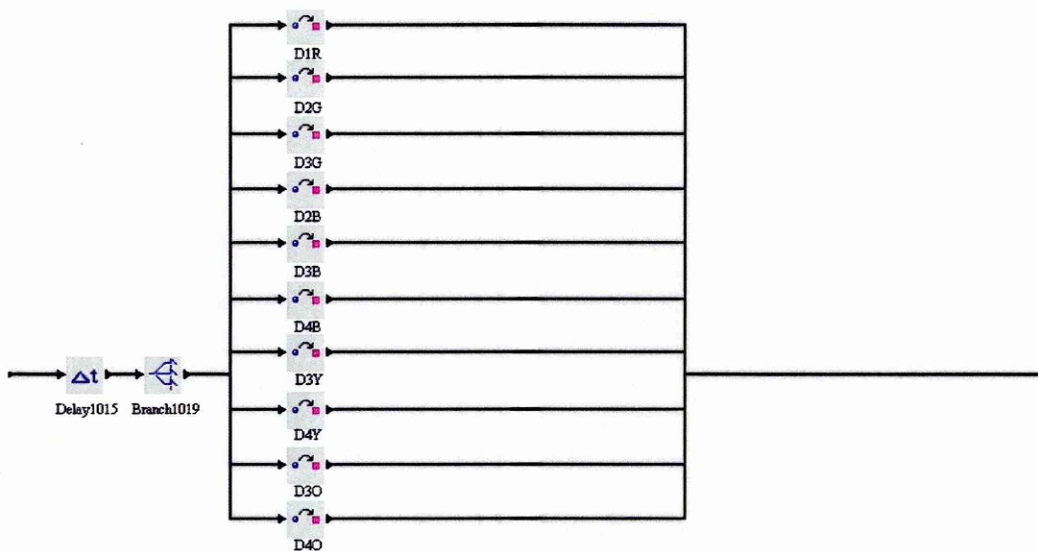


Figure 14: Differentiation of coloured paper into different dividers

After these have been trimmed, laminated and punched they are stored to the general Stores, and then they proceed to the next stage which is the Assembly Department. In this department there are three workstations where the final assembly of the components is happening.

The next stage in the process is the assembly department of the model where the formation of the final products is taking place. Figure 15 shows the overview of this department and it can be seen there are three different workstations.

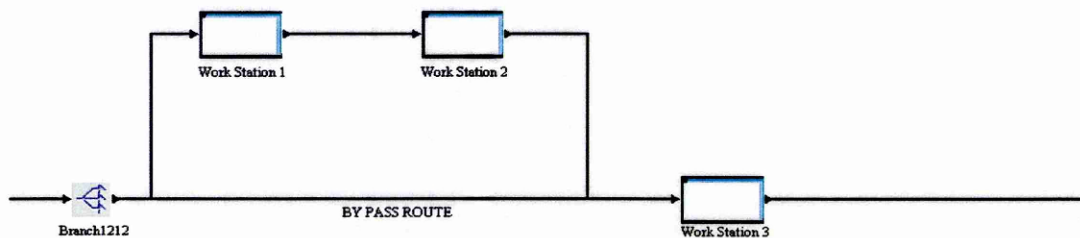


Figure 15: Overview of the Assembly Department

In the workstation 1 the trimmed covers and spines are teamed with the appropriate binders and are proceeding to the workstation 2 where the spines and covers are inserted into the binders and all together as a subassembly are proceeding to the workstation 3 where the dividers and tabs are placed as well. This is illustrated in Figure 16 where it can be seen also the holding area for the Inventory which is another crucial measurement in order to highlight the difference between the models.

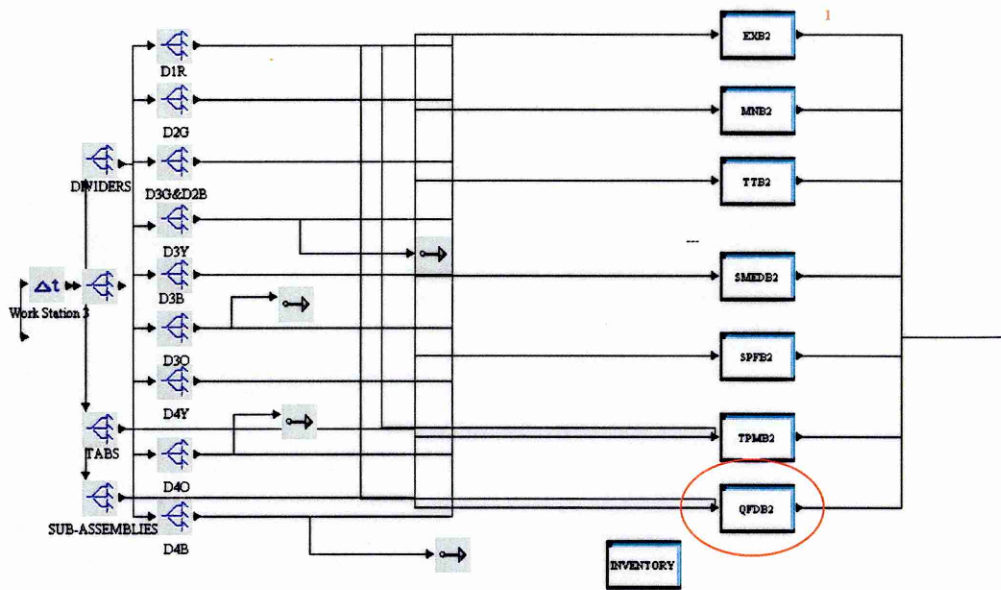


Figure 16: The inside view of the workstation 3

Each one of these process blocks as the one highlighted with the red circle in Figure 16: The inside view of the workstation 3, has several sub-processes which are illustrated in the following Figure 17;

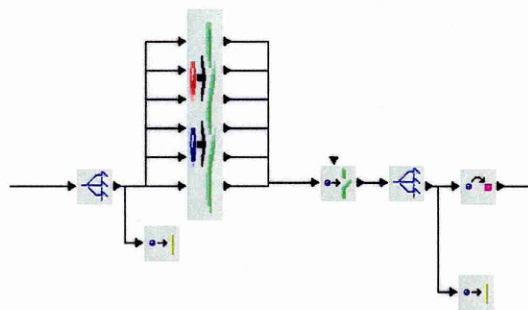


Figure 17: Inside View of the process block in the final assembly of the end product

After this procedure has finished the final products are assembled and are treated as one product with different characteristics, which are then proceed to the Dispatch where they either dispatched to the customer or stored for future dispatch, as it is shown in the following Figure 18.

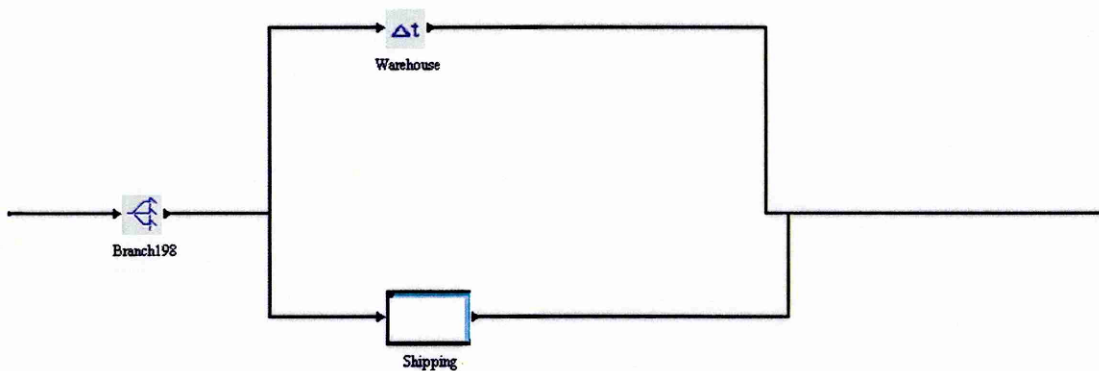


Figure 18: Final Stage of the Model Warehouse and Shipping

5.2 Step 2 - Building the Mixed Pull Model

After having completed the building of the Push Model, the Mixed Pull Model has to be build. The ways that the Mixed Pull Model had to be built as well as the methodology that have to follow from the programmer of the model are detailed in this section of the report. Firstly the methodology had to be explained as well as the expression language that is used. After that has been completed the way that the model was build, layout, has to be detailed as well so that to guarantee the fully understanding of the reader.

5.2.1 Methodology of Mixed Pull Model

Several elements of the push model have been transferred to the Mixed Pull model, as well as many of them have been eliminated. Whenever it was believed that the elements have to be kept the researcher of this project has kept them either intact or slightly modified so that to ensure correct functioning of the model. The basic elements like the Bill of Material in Figure 3 as well as the Divider Configuration Table 2, of the end product as well as the rules have been kept intact for this model.

The major difference is that the Mixed Pull Model has to simulate both Push as well as Pull properties and in order this to be successful both logic and rules have to be followed. As in the Push Model there is a logic that needs to be followed the same is happening with the Mixed Pull Model as well. The essential logic as well as an overview of the layout that needs to be followed is illustrated in Figure 19 that follows;

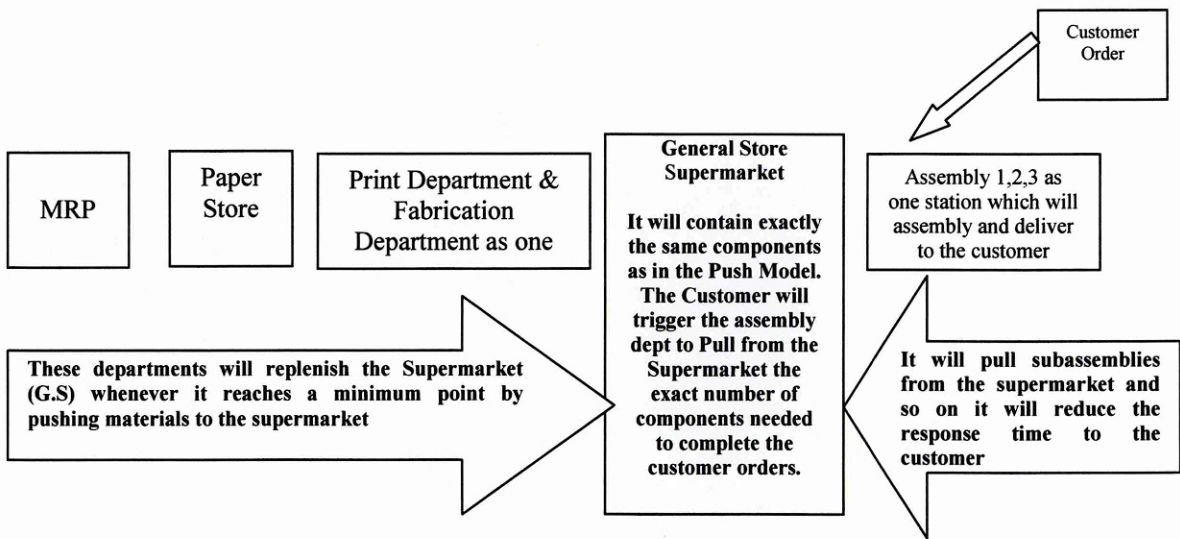


Figure 19: Logic and Layout that Mixed Pull Model has to follow

Major differences except the layout, is the expression language that is used to generate the entities of the model as well. The following expression language has to be followed in order to achieve that. Figure 20, illustrates the place that this expression language have to be placed and after the actual expression language used is following wherever there is an asterisk after the name of the expression there is inside it expression language;

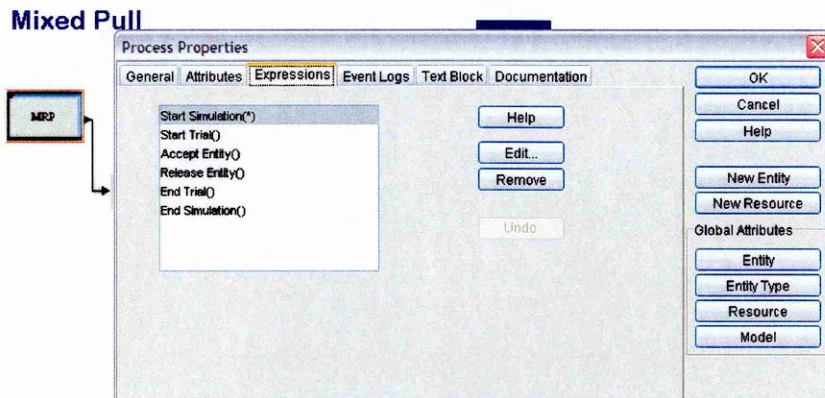


Figure 20: Inside the MRP process block

Part of the Expression Language that is inputted at this position follows and the complete expression language is shown in Appendix 2.

Note: again the expression language is highlighted with blue and the explanation of it is following by using normal black lettering.

{White}

```
Model.SUPERMAX := FLOAT(Model.SUPEREXB2MAX +  
Model.SUPERMNB2MAX + Model.SUPERTTB2MAX +  
Model.SUPERSMEDB2MAX + Model.SUPERSPFB2MAX +  
Model.SUPERTPMB2MAX + Model.SUPERQFDB2MAX);  
Model.WHITE := 10.0 + FLOAT(CEIL((Model.SUPERMAX/2.0) +  
(Model.SUPERMAX/10.0)));
```

This expression language makes sure that the MRP is generating the correct amount of entities for the Buffers in the Super-Market. In the Supermarket there are twenty nine positions, gates, which they act as buffers before the assembly so that to minimise the response time to complete the customer order i.e (LAMINATOR) is the sum of the position of the Supermarket EXB2 plus MNB2 plus TTB2 plus SMEDB2 plus SPFB2 plus TPMB2 plus QFDB2 divided by 10 since the spines are getting trimmed down to ten individual ones after they have been laminated. The same logic is followed for the rest of the eleven entities that have to be generated. The word (Model.SUPEREntity NameMAX) is used in order to indicate that the replenishing quantity will be not greater than the maximum allowed quantity in the buffer held at the supermarket.

In order to make sure that the correct amount of products are created and so on there isn't a case of generating random materials, the following code had to be inputted so that to make sure that it calculates them correctly. In the spreadsheet that was created there is an area that is similar to the Table 2 and that is indicating to the system which binder has to create for which binder. For example the D1 position in the area in the Excel Spreadsheet "INPUTSSS" is the D1R divider, which needs to be generated as the sum of the End Products; EXB2 plus MNB2 plus TTB2 plus SMEDB2 plus SPFB2 plus QFDB2 and finally plus the TPMB2, and so on, part of the expression language that is used is following and the complete form of it is shown in Appendix 3.

```
Model.SPINES := CEIL(Model.EXB2N/10.0) + CEIL(Model.MNB2N/10.0) +  
CEIL(Model.TTB2N/10.0) + CEIL(Model.SMEDB2N/10.0) +  
CEIL(Model.SPFB2N/10.0) + CEIL(Model.QFDB2N/10.0) +  
CEIL(Model.TPMB2N/10.0);
```

Inside the MRP process block there is also another generate function which is allowing the system to function as a push system at this point. This is illustrated in Figure 21 that follows;

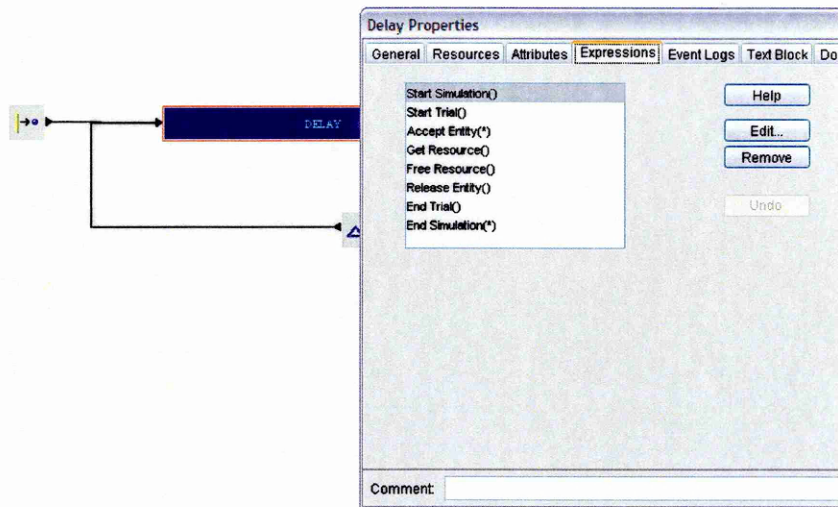


Figure 21: inside view of the MRP process block to illustrate the place that the expression language is placed

The expression language that is placed into this block is the following;

```
IN : STRING;
X,Y : INTEGER;
N := N + 1;
```

IF N=1

This allows to the system to generate from the spreadsheet entities which are in a form of STRING of characters and not a single number and that the X and Y numbers are Integers and not Real numbers.

```
Model.ORDERXL := OpenSpreadsheet("Input","C:\\ORDERS.xls");
```

FOR X := 1 TO 12

This part of the expression language makes the model to read from the ORDERS.xls for X = 1 until 12, which are the orders by months as the sponsoring company runs the model for 12 periods.

```
ReadFromSpreadsheet(Model.ORDERXL,"ORDERS 2005",10*X,4,IN);
Model.OD[X] := IN;
ENDFOR;
```

FOR X := 1 TO 12

```
IF STRTOREAL(SUBSTR(1,2,Model.OD[X])) =
STRTOREAL(SUBSTR(1,2,DateTime))
```

```
    ReadFromSpreadsheet(Model.ORDERXL,"ORDERS 2005",((10*X),3, Y);
Model.EXB2O := Y;
    ReadFromSpreadsheet(Model.ORDERXL,"ORDERS 2005",((10*X)+1),3, Y);
```

```

Model.MNB2O := Y;
  ReadFromSpreadsheet(Model.ORDERXL,"ORDERS 2005",((10*X)+2),3,Y);
Model.TTB2O := Y;
  ReadFromSpreadsheet(Model.ORDERXL,"ORDERS 2005",((10*X)+3),3,Y);
Model.SMEDB2O := Y;
  ReadFromSpreadsheet(Model.ORDERXL,"ORDERS 2005",((10*X)+4),3,Y);
Model.SPFB2O := Y;
  ReadFromSpreadsheet(Model.ORDERXL,"ORDERS 2005",((10*X)+5),3,Y);
Model.TPMB2O := Y;
  ReadFromSpreadsheet(Model.ORDERXL,"ORDERS 2005",((10*X)+6),3,Y);
Model.QFDB2O := Y;
ENDIF;
ENDFOR;

```

This indicates to the system that it has to read from another excel spreadsheet, which is again supplied with the models as the ORDERS.xls file, named ORDER, from the specific worksheet ORDERS 2005, and perform the specified calculations before it starts generating the entities.

```

FOR X := 1 TO (Model.EXB2O + Model.MNB2O + Model.SMEDB2O +
Model.SPFB2O + Model.TPMB2O + Model.TTB2O);
FireTrigger("D2G-GATE");
ENDFOR;

```

```

FOR X := 1 TO Model.QFDB2O;
FireTrigger("D3G-GATE");
ENDFOR;

```

```

FOR X := 1 TO (Model.EXB2O + Model.MNB2O + Model.SMEDB2O +
Model.SPFB2O + Model.TPMB2O + Model.TTB2O + Model.QFDB2O);
FireTrigger("D1R-GATE");
ENDFOR;

```

This expression language allows to the model whenever for example, the Model.EXB2O which is the Order received from the supermarket for replenishing the buffer, to fire the trigger of the gate as many times as appropriate to cover the amount that has been ordered. The same is happening for all the seven end products, which are firing all the twenty nine gates available at the supermarket.

In the Supermarket there are twenty nine gates that they are acting like buffers, the use of them was essential since part of the properties of a gate is the fact that there is a trigger that can be fired whenever this is appropriate by using the appropriate expression language in two different places the Accept Entity and Release Entity part as follows;

Accept entity

Model.NIND2GGATE := NumberIn;

ORDERED := FALSE;

Release entity

Model.NIND2GGATE := NumberIn;

IF Model.NIND2GGATE < Model.SUPERRO AND ORDERED = FALSE

This part says to the model that if number in gate D2G, green divider for position two gate, check the quantity and if it is smaller than the supermarket order then order the extra amount from the generate by making the following calculations;

{Green}

Model.SUPERMAX := FLOAT(Model.SUPEREXB2MAX +
Model.SUPERMNB2MAX + Model.SUPERTTB2MAX +
Model.SUPERSMEDB2MAX + Model.SUPERSPFB2MAX +
Model.SUPERTPMB2MAX);

GenerateEntity("SOURCE","Green",CEIL(Model.SUPERMAX/2.0));

If the ordered quantity for the supermarket from the generate block has arrived then there is the correct amount in the buffer and then, TRUE, stop ordering expressed in expression language as follows;

ORDERED := TRUE;

ENDIF;

After this part of the system has been completed then the system is ready to cover the order that has been placed to the supermarket from the excel spreadsheet ORDER.xls.

With this way the system can simulate both push before the supermarket in order to fill in the buffers of the supermarket as well as Pull after it since the customer order is the one that pulls end products from the assembly all the way back to the supermarket.

5.2.3 Model 2: Mixed Pull Model

After the expression language of the model has been explained into great detail the actual layout of the model is going to be explained in this section of the report. As it was shown in Figure 19, the layout has to be dramatically changed in order to correspond to the desired one set by the sponsoring company which is clearly illustrated in the Top View of the Mixed Pull Model (Figure 22) that follows;

Mixed Pull

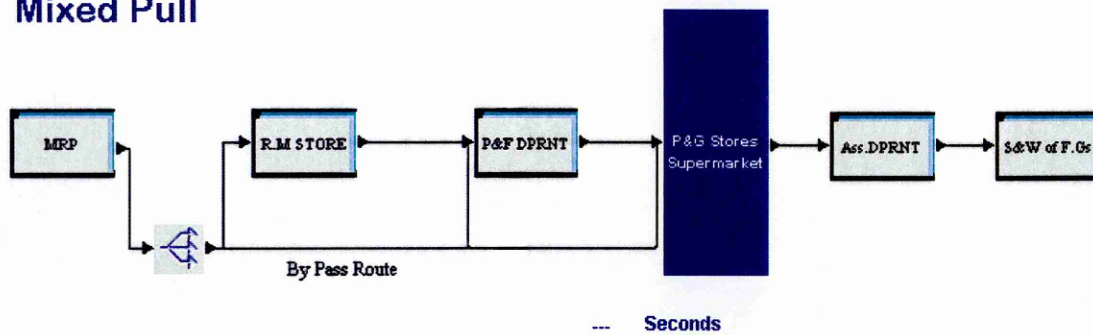


Figure 22: Top View of the Mixed Pull

As it can be seen there are some different stores in place like the raw material one that holds the papers that need to be inputted to the system. Also the P&G Stores/Supermarket had to be introduced in order to highlight the different areas of the model. Before the supermarket the system acts like a push system and after the supermarket it acts like a pull system. The Supermarket acts as a time buffer between the two specified areas. Also some of the departments have been coupled so that to show that there are no travelling times between them which is not the case in the Push occasion. The P&F department is the combination of the print and fabrication departments which now act a single department by changing the layout between them as well as eliminating one store room, the print stores.

The new layout of this department is shown in Figure 23;

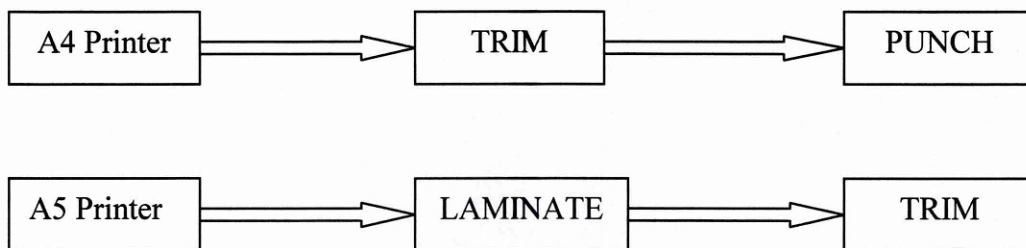


Figure 23: New Layout for the P&F Department

Although there is this different layout in the P&F Department the only essential difference to our actual layout for the Mixed Pull model is the elimination of the Print Stores and the elimination of the travelling time between the two departments. This is done with the time efficiency in mind since the redesign as well as the connection of the various components together it time consuming procedure and sometimes it generates mistakes due to human factor. In reality the department now looks like the one in Figure 24 that follows;



Figure 24: Inside view of the P&F Department which now acts as one department

The Raw Material department is illustrated in Figure 25 that follows and it has the same function as detailed in the explanation of the Push Model.

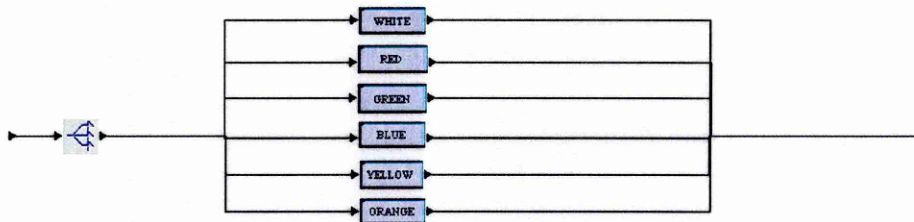


Figure 25: R.M Store

Another big difference in the model is the introduction of the supermarket that acts as the time buffer between the two different areas of the organisation, Push and Pull. In this department there are 29 gates that act as buffers and hold a specified maximum quantity which is there to cover the demand for the customers' orders. These gates/buffers have a maximum holding stock and a minimum reorder point, when the reorder point is reached the gate/buffer fires its trigger so that to be replenished from the generate block, when the maximum point has been reached then the generation stops. Figure 26 illustrates the inside view of the Supermarket;

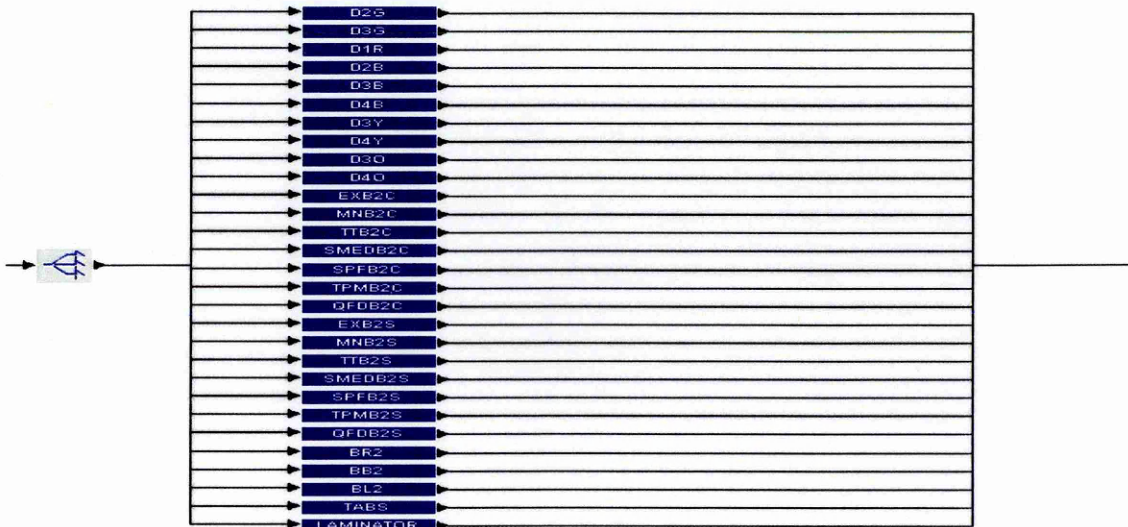


Figure 26: Inside the Supermarket

By inputting part of the expression language in the expression mode of the gate the system is able both to supply materials to the assembly area as well as replenish its buffers from the rest of the system.

The assembly area has remained the same in layout as in the Push Model with the only difference to exist in the reorganisation of the tasks in each of the workstations as well as the elimination of the travelling times.

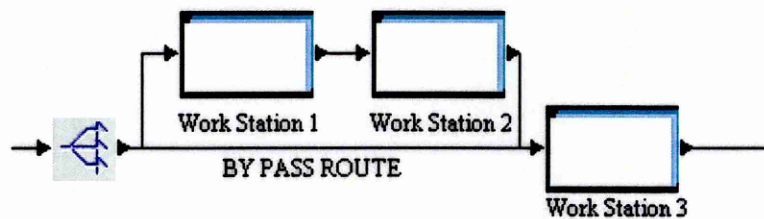


Figure 27: Inside the assembly department now acts as one workstation

The rest of the model warehouse and shipping is exactly the same as the Push Model which anyway it does not play any significant role to the models since they do not have any times attached to them.

5.3 Step 3 - Improving Simulation Tools by Creating a VSM Icon Library

In this section of the report the procedure followed for the creation of the Value Stream Mapping Icon Library is going to be detailed. As the construction of the models has finished, the next step that the researcher has to take is the enhancement of the models by the use of the Value Stream Mapping Icons. This will make the models easier for everybody who has lean manufacturing knowledge to follow the models in greater detail. This is currently missing from the models since the nature of the default icons currently used is such that makes them difficult to follow if you are not familiar with the software. The use of VSM Icons will make them more appealing to a wider group of people.

The structure of this section is very easy to follow since it starts from the fundamentals of what is the value stream mapping, proceeds to the explanation of why the value stream mapping is important.

5.3.1 What is Value Stream Mapping

In order the foundations to be placed the definition of what is value stream mapping is following by the words of Rother & Shook (2003), *“A value stream is all the actions, both value adding and non-value adding currently required to bring a product through the main flows essential to every product: the production flow from raw material into the arms of the customer and the design flow from concept to launch.”* By this definition for the value stream mapping, it is obvious that in order to make this activity to an organisation you have to breakdown every element of your business and translate it into quantitative elements in a paper. This will allow the organisation to understand every value adding and non-value adding activities in its system.

This is very important for an organisation since it will be in a position the people of the organisation to see outside the box of only one operation and realise the significance of each interrelated procedure or process to the product and the effects that these have at its performance. By having a clearer view of the bigger picture an organisation is trying to improve the overall production picture and not just some individual processes.

In order to truly follow the whole procedure until the product reaches to the customer hands, an organisation has to map the value stream for a product across many firms and even more individual facilities. As this is very optimistic and it is not always feasible in the real world, the most common practice for the everyday companies is to value stream their products with a “Door to Door” approach and including the shipment to the customer’s plant as well as the supply of the parts and materials to the organisation itself. By doing so it means that the value stream mapping is easier and faster to be done and sometimes this is all you need to understand the situation of your organisation. In

the words of Rother & Shook (2003), *“This is a good level at which to begin your mapping and lean implementation effort.”*

5.3.2 Benefits of Value-Stream Mapping as a Tool

“It helps you visualise more than just the single process level in production.” Rother & Shook (2003), this is happening due to the fact that, in order to successfully map the value stream of a product, you need to map its flow through every stage of the process. This allows a clear overview of the whole process/es and not just in a spot of the whole picture i.e. instead on focusing only in a press operation that a product passes, it has to map and the rest of the operations like the welding, assembly, packaging and so on in order to see their correlation with each other.

As the elimination of the waste is the core competence of a lean organisation the identification of it, is more than essential for this organisation. The exact identification of the volume, in quantitative form, real number and not just a rough estimation of it, as well as the sources of this waste is also critical since by Rother & Shook (2003), *“It helps you see more than waste”* and this is something that will point out the importance of the elimination to the organisation. The effective value stream mapping will assist to clarify these and make the organisation aware about its importance.

“It provides a common language for talking about manufacturing processes” Rother & Shook (2003), and this is something of the essentials that the sponsoring company wants to achieve with the introduction of the VSM Icons into their simulation models. So it is very easy to explain to everybody about the problem whether or not they have adequate knowledge of the manufacturing processes. This makes it easy as well as common goal for everybody related to the production and the finances of it without becoming boring and uninteresting to the non specialist.

As Rother & Shook (2003), says *“It forms the basis of an implementation plan”* which makes it even more valuable for an organisation since it gives the exact guidance in order not to forget a step of change while trying to achieve the overall implementation. It helps you maps your trip to fully implementing the changes step by step as well as indicates forgotten steps while you implementing it. Without it is like *“trying to build a house without a blueprint”*.

And finally it allows you to link the information flow with the material flow which is unique and none other lean tool can achieve that in the words of Rother & Shook (2003), *“Value-Stream Mapping is a qualitative tool by which you describe in detail how your facility should operate in order to create flow.”* An organization can succeed that by comparing the current state of the facility in terms of flow with the desired flow of the facility, that is a clear picture of what needs to be done which is created and then it is much easier to follow by everybody as well as give motivation to achieve the change since the future is in drawn onto paper.

5.3.3 Value-Stream Mapping Icons Used to Form the Library

After research of the available value stream mapping icons, the researcher of this project was able to identify four main categories of twenty nine in total symbols. These four main categories as well as the explanation of each category's icons are detailed in four sections at Appendix 4;

5.4 Summary

By summarising this chapter of the report it is vital to say that the researcher of this report in order to be able to construct the models and make sure that they run as appropriate the attention to the detail had to be kept at the maximum. There are many rules that the models have to oblige with, not to forget the major rule of all the Push and the Mixed Pull ones. There are many other smaller but very essential ones like the batching of the products that need to follow i.e. the 10 spines per white sheet, the two covers per coloured sheet as well as the two covers per white sheet. Furthermore, the fact that these smaller details make the model to be much more complicated than what was anticipated to be, before its construction was started.

The use of the information provided from the sponsoring company as well as the attention to the detail of the researcher, made this part of the project rather successful considering the limitations that are detailed in the conclusion section 9.2. The Push model is fully functional and the Mixed Pull model is more than 80% completed and ready to run. The limitations of the time in conjunction with the lack of support on time forced the models not to be completed.

The need for extensive use of expression language was also very big in order to make the program push and pull from the different stations of the model. this is something that required even more attention since there are crucial calculations i.e. for the calculation of the spines that the numbers have to rounded up when divided by 10, so that whole white sheets are entering the system and the printing pattern remains as the appropriate, 10 spines of the same end product in one of the white sheets. This created a lot of problems especially with the validation of the models since the incorrect number was many times have been calculated due to bad programming. The command (OUTPUT(Entity.Name);) at the stage of validation of the models proved to be more than priceless for the researcher of this project. By using this command whenever it was appearing an irregularity to the models and by introducing it in the Acceptance or Release of the Entities at every element of the models, the researcher was able to track the irregularity down and correct it.

The validation of the models was a procedure that took a big time share from the allocated time to build and run the models. This is due to the fact that the combinations of the complicated calculations in excel spreadsheets as well as the complicated routings

in the models are such that the generation of mistakes during the programming is easy to be made.

All in all the software seems to have great capabilities far greater than what the researcher of this project was able to explore, but the extensive use of expression language and mathematical computation which made it even more difficult for the researcher to explore them.

6 Stage 2: Evaluate the Effectiveness of the Templates & Models within the Company

Having completed the work that needed to be done for the completion of the electronic form of the “Simply Lean” workshop, the evaluation of the models created as well as the template library that was created have to be performed. The initial plan was to conduct a survey which will involve both the sponsoring company as well as the participants of one or more Simply Lean Workshops. The survey was planned from the researcher to be materialised in the form of a questionnaire that was going to be distributed in person from the researcher to the facilitators, sponsoring company, as well as the participants, client company/s of the facilitators after the completion of the workshop.

6.1 Interview Technique and Medium

Due to the limited time for the completion of the project the survey could not be carried out. As an alternative the evaluation of the delivered package was conducted through an interview. As this is the last chance that the researcher will have to conduct the evaluation there has to be a clear plan on how to conduct the interview correctly and try to make the most out of it. The following sections will describe the whole procedure that was followed in order to conduct the interview as well as the way that the feedback will be analysed and documented.

6.1.1 Decision for the form of interviewing to be conducted

At first the interview might seem as a simple task as well as obvious to be taken. That is not the case since the interviewer has to co-ordinate the conversation in order to obtain the desired information from the interviewee. In order this to happen very detail planning of the interview has to be done. It has to be clear to the interviewee of his/her position to the whole manner, the interviewee by the words of Gubrium & Holstein (2002) *“the interviewee provides the answers...the interviewee’s obligation is not to manage the encounter or to rise queries”*.

There are several forms of interviewing and depending on which it is selected to conduct the preparation for it is different. Three of them are going to be detailed at this section so that to validate the selection of the researcher of this project.

One of the available forms of interviewing is the Survey Interviewing, which is commonly done either as face to face or as in the form of a telephone survey or by mailing questionnaires. Although the *“face to face surveys used to be the dominant mode of survey data collection until the 70s...nowadays the telephone interviewing is more viable and practical”* Gubrium & Holstein (2002). The face to face interviews are more flexible, compared to the telephone interviews, in terms of question content and they *“tend to generate higher response rates and are more appropriate for long*

interviews with complex questions” Gubrium & Holstein (2002), but in the other hand the telephone interviews are cheaper easier to manage and require shorter period for the collection of the data.

The second form of interview that was considered from the researcher of this project was the Qualitative Interviewing. This form of interview “is based in conversation with the emphasis on researchers asking questions and the interviewee answering” Gubrium & Holstein (2002). It is quite similar to the way that the standardised survey interview is formed but unlike the survey interview “*the epistemology of the qualitative interview tends to be more constructionist than positivist.*” Gubrium & Holstein (2002). The aim of the Qualitative Interviewing is not to retrieve information but to make the participant to make a meaning out of his own words and express his personal beliefs for the matter. The significant difference to the Survey interviewing is that the Qualitative Interviewing has, is “*open-ended in the sense that is more concerned with being attuned to who is being travelled with, so to speak, than with setting out a precise route for all to follow, as in the Survey Interviewing.*” Gubrium & Holstein (2002).

The third and final form of interview that the researcher considered is the so called In-Depth Interviewing. The In-Depth Interviewing tends to be of relatively longer duration than the other two forms and “*seeks to build the kind of intimacy that is common for mutual self disclosure*” Gubrium & Holstein (2002). It is the most difficult to conduct and seems to require greater interviewing abilities from the facilitator so that to be able to gather the information needed from the interviewee. “*In-Depth Interviewing offers great advantages, but it also entails several risks and dangers as well as some distinct ethical considerations*” Gubrium & Holstein (2002).

6.1.2 Medium of Conducting the Interview

The decision remain to be made at this point is whether the interview will be conducted face to face or through the telephone. At this section the argument In-Person versus Telephone interview will be developed. There are two tasks that the researcher has to overcome successfully, “*the persuasion of the interviewee to participate to the interview and the second which in the specific case of the researcher is the important one is to bring out the information from the interviewee*” Gubrium & Holstein (2002). The first task is not considered to be difficult since there is already an agreement with the interviewees to participate to the interview. The second task that the researcher has to resolve, so that to be able to conduct the final evaluation of the end product, is the medium that the interview will be done through.

The criteria for deciding whether the interview will be conducted in person or through a telephone are the following;

1. The type of interview which is already selected to be the Survey Interviewing

2. The type of information required to be gathered
3. The available time from both parties, interviewees as well as interviewer
4. The place that the interviews can take place
5. the complexity of the questions

The previously listed criteria have been judged as essential for the interviewer to answer in order to decide the medium that the interview will be conducted.

6.1.3 The advantages of telephone versus in-person interview

Amongst other advantages Gubrium & Holstein (2002) are listing the following advantages;

1. *Better interviewer uniformity in delivery* – the tone of the voice and delivery of interviewers can be more effective in the success of the interview against the one conducted in person. As well as the fact that the time is shorter than the in person interview allow to the interviewer to monitor better the outcome of the interview.
2. *Greater standardisation of questions* – it is believed that the researcher during the telephone can control in greater degree over the interview quality.
3. *Greater cost efficiency and fast results* – it is obvious that the use of telephone is much faster as well as much more cost effective than travelling to the interviewee to conduct the interview.

6.1.4 The advantages of in-person versus telephone interview

Amongst other advantages Gubrium & Holstein (2002) are listing the following advantages;

1. *More accurate responses owing to contextual naturalness* – by making the interviewee to feel more relaxed the accuracy of the answer is increasing.
2. *Greater likelihood of self-generated answers* – some of the questions are planned so, to give little or no freedom to the respondent to answer.
3. *Greater effectiveness with complex issues* – due to the fact that there is a better connection since participant looks the interviewer, this easiness allows him to place his answer more accurately.

4. *More thoughtful responses* – more time to respond as well as the previously mentioned easiness can occur to a more thoughtful response than when interviewed from the telephone.

6.1.5 The selected form and medium to conduct the interview

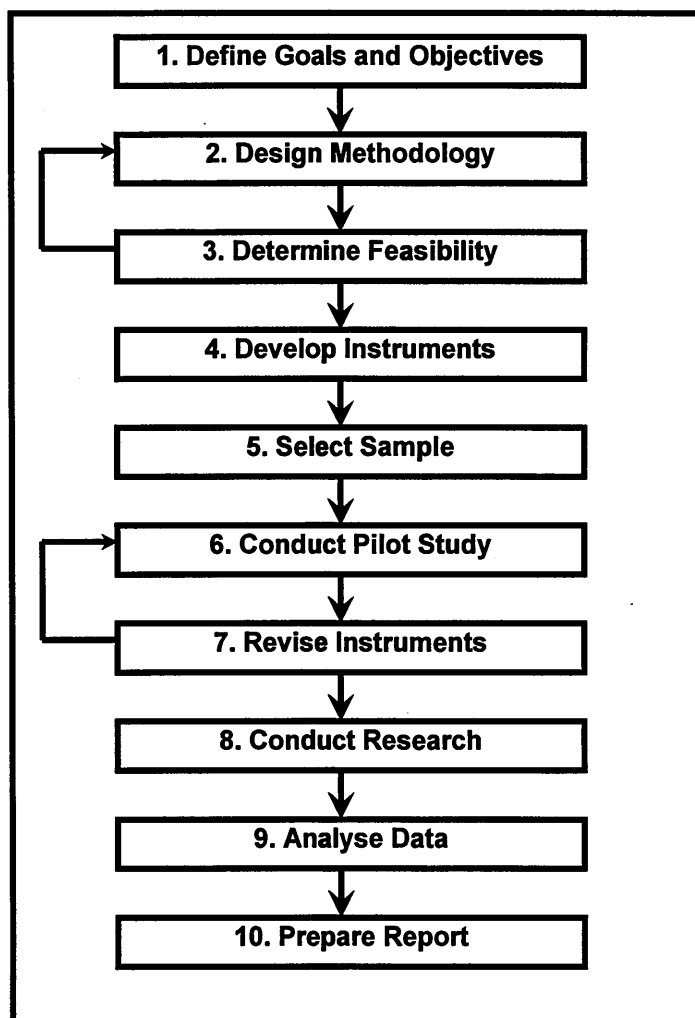
The decision after considering all the above criteria as well as the advantages of each of the mediums, very carefully was to conduct the interview through the telephone, since there is time limitation for the project to be completed. Also the very loaded schedule of the interviewees did not allow the researcher to conduct both the interviews at the same day which becomes even more difficult due to the fact that the interviewees are based in different parts of the country with a distance between them of over 150 miles, which makes it impossible to conduct them at the same day.

After researching in the three interviewing techniques the interviewing form that the researcher seems to be more comfortable with is the Survey Interviewing, but at the end of the interview there will be adequate allocated time that will allow the interviewee to add his personal comments for the subject. This seems to be viable to this case since the interviewees are going to be Mr. Peter Rice director of BRM³ the sponsoring company as well as the Process Improvement coordinator of the company Mr. John Britton and Mr. Steve Allen, a Simulation Specialist. All of the interviewees have been in contact with the interviewer throughout the project and know everything about the problems as well as they have seen the end product.

6.2 Method for the Questionnaire Design

A questionnaire will have to be developed to act as a template which will assist the researcher/interviewer to make sure that he will conduct all the questions to both the participants as well as to sufficiently document the answers that the participants will supply, in such a manner that the data gathered will be easy to be analysed when they will be revisited after the interviews have been completed.

It is very important that the template questionnaire is very well designed since that will assist the increased validity of the responses, which is very important for the outcome of the interview. Figure 28 illustrates the method with which the questionnaire will be developed in an attempt to successfully design the questionnaire and try to guarantee good odds for a good validity response rate;



Reference: L. B. Bourque & E. P. Fielder "How to Conduct Self-Administered and Mail Surveys" 2nd Edition, 2003, SAGE Publications

Figure 28: Method for the development of the design of the questionnaire

The other elements of the questionnaire that have to be considered in order to be able to generate a good as well as effective questionnaire are the following;

6.2.1 Length of a Questionnaire

After a thorough research, the researcher of this project understood that the length of the questionnaire is something crucial for its success "*As a general rule, long questionnaires get less response than short questionnaires.*" (http://www.studentbmj.com/back_issues/0601/education/187.htm). Therefore the interviewer has to be careful since one of the disadvantages of the telephone interviews is the fact that in order to keep the interest of the participant it has to be short enough to avoid misleading responses. Also there has to be long enough in order to allow the correct amount of information to be gathered.

6.2.2 Question Wording

Another very important element in the design of a questionnaire is the way that the questions are written in order to avoid leading the interviewee to the desired for the researcher answer, “*researchers strive for objectivity in surveys and, therefore, must be careful not to lead the respondent into giving a desired answer*”, (http://www.studentbmj.com/back_issues/0601/education/187.htm).

6.2.3 The order of the questions

Also the “*Items on a questionnaire should be grouped into logically reasoned sections*”, (http://www.studentbmj.com/back_issues/0601/education/187.htm), since that will allow a better flow in the interview as well as make the participant focused in one subject at the time and will make him produce more detailed information for the researcher to analyse. This rule in the questionnaire is beneficiary for both parties, the participant to feel more relaxed and the interviewer is easier to record the answers and so on easier to analyse the responses. Grouping questions that are similar will make the questionnaire easier to complete. “*Questions that use the same response formats, or those that cover a specific topic, should appear together.*”, (http://www.studentbmj.com/back_issues/0601/education/187.htm).

6.2.4 Types of Questions

Researchers use three basic types of questions: **multiple choice**, **numeric open end** and **text open end** (sometimes called "verbatim"). Examples of each kind of question are in Figure 29 that follows;

Multiple Choice

1. Where do you live?

- North
- South
- East
- West

Numeric Open End

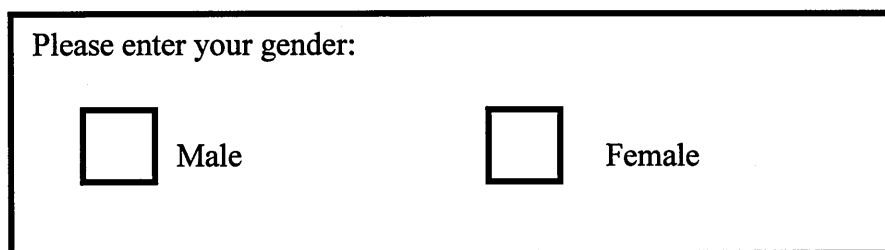
2. How much did you spend on groceries this week? _____

Text Open End

3. How can our company improve its working conditions?

Figure 29: Examples of formation of questions (Bourque & Fielder, 2003)

There are also commonly used the **Dichotomous Questions**- which are questions that have only two possible outcomes i.e. Figure 30 that follows;



Please enter your gender:

Male Female

Figure 30: Example of a dichotomous question (<http://www.surveysystem.com/sdesign.htm>)

6.2.5 Brainstorming Session

One very important step for the design of the questionnaire is the formation of the list of the questions that have to be asked. In order for this to be successful “*a brain storming session is recommended to compile a list of possible questions*“, (Bourque & Fielder, 2003). That will allow the researcher to identify which questions will assist him to gather the information to fulfil the objectives of the interview and which ones are unnecessary.

In order to successfully complete this elimination procedure of the unnecessary questions, Bourque & Fielder, (2003) suggest asking the following series of questions;

- *Is the question necessary and useful?*
- *Does the question actually ask two or even more questions?*
- *Are more questions required to simplify the original question?*
- *Are the questions relevant to the respondent, and will they have access to the required information?*
- *Are the questions too general? Do they need to be more specific?*

6.3 Design for the Survey Interviewing

This section will try to detail the procedure that was followed in order to successfully create the template questionnaire which will assist the researcher to successfully assess the effectiveness of the created electronic package “Simply Lean”.

6.3.1 Key Performance Measurement for the Effectiveness of the workshop created

Before the creation and the categorisation of the questions can happen the most important step that needs to be taken is the identification of the key performance measurements against which the package needs to be assessed. The elements of the package that need to be assessed are the following:

1. Push Model
2. Mixed Pull Model
3. VSM Icon Library

In order for this evaluation of the three elements to be assessed successfully the need for reminding the key objective of the “Simply Lean” Workshop is vital at this stage.

The workshop is a tool which will assist the exploration of how “wide variety low volume production” could accommodate a lean approach and how it can be accommodated a Pull logic. The workshop has a strictly lean training nature and it does not have to do anything with training in simulation. The discrete event simulation is used only for the purposes of the illustration of the experiments and the effects that the changes have to the system.

After a brainstorming session the areas that need to be targeted in these three elements of the workshop are the following;

- The level of detail against the physical model currently used
- The success of illustrating the attributes of Push and Mixed Pull principles
- The success of highlighting the problems created by the batch production
- The user friendliness of the created workshop

6.3.2 Justification for Questions

Based on the previous analysis as well as the theory and rules obtained through the sections 6.1 to 6.2.5 the researcher was able to create a questionnaire template. The justification of the questions that formed the ingredients of this template will be detailed at this section.

Push/Mixed Pull Models

Question 1: After having evaluate the Push/Mixed Pull model, what do you think that the success factor in achieving the level of detail against the currently used model? Answer in % value and also commenting will be allowed.

With this question the researcher is trying to achieve the quantitative answer for the specific topic which will allow him to quantify the success of the models. Also the commenting will provide the back up information for the value given.

Question 2: After having evaluated the Push/Mixed Pull model, what do you think is the success factor in:
Illustrating the Push/Mixed Pull Principles?
Illustrating the effects that the batch production has to the system?

Answer should be in % value as well as commenting for the answer should be allowed. With this question the researcher is trying to take a quantitative answer which will allow him to measure the success of the models at this field. Also the commenting that will follow it will allow him to use the comments of the interviewees in order to backup their %score for the model.

Question 3: Which do you think are the strong points of the Push/Mixed Pull models?

With this way the researcher will be able to gather information, which can be used in order to assess the computer simulation model against the claimed advantages listed at the literature review section 3.6 of this report.

Question 4: Which do you think are the weak points of the Push/Mixed Pull models?

With this way the researcher will be able to gather information about both the success of the models as well as compare the weak points addressed from the interviewees against the claimed ones in section 3.7 of this report.

Question 5: Is the Push/Mixed Pull models user friendly? Is it useable for the training purposes you intent to use it?

With this question the researcher trying to evaluate the models against their primary purpose of training.

The above questions they will be addressed for both the models as different questions (10 in total) so easiness of recording the results as well as the guidance of the interviewee through the interview can be achieved.

VSM Icon Library

Question 11: What is the success of the library against your expectations? Is it complete?

With this way the % value that will be supplied from the interviewee will be sufficient to quantify the success of the library.

Question 12: Is the library user friendly?

With this way the researcher will get some extra comments for the icon library.

6.4 Results of Interview

In this section the results of the interview are analysed based on the responses of the three participants. Their views are going to be listed one after the other so that the clarity of their views is going to be achieved.

6.4.1 Mr. Peter Rice

Push Model

Q1. After having evaluate the Push model, what do you think that the success factor in achieving the level of detail against the currently used model?

Answer: I believe that the model mimic very successfully the current model used by our company in the regions of 90% plus. The only limitation is the fact that it needs some tidying up which will make it look better aesthetically.

Q2. After having evaluated the Push model, what do you think is the success factor in?

1. Illustrating the Push Principles?
2. Illustrating the effects that the batch production has to the system?

Answer:

1. 100% it is doing exactly what is claimed in the workshop's theoretical part
2. 80% it is illustrating the effects of the batch production like inventory levels etc, but it could be more visually strong, perhaps some graphs, or a interactive table on the screen with the outputs will be great. Of course I can understand that this was not in the original project specifications.

Q3. Which do you think are the strong points of the Push model?

Answer:

- Accuracy of the model in both the geography and the process times as well as the product routing
- Speed that the experiments can be run. Just a case of changing 7 figures in the excel spreadsheet
- Allow the participants to see the changes in the layout as well as the effects that these have to the system
- Simplicity of the model so even if not familiar with the process

Q4. Which do you think are the weak points of the Push model?

Answer:

- Nothing fundamental in the logic or the accuracy of the model
- Some more tidying up for the aesthetics shake

Q5. Is the Push model user friendly? Is it useable for the training purposes you intent to use it?

Answer: In this manner it is very successful and as I said it is easy for both the facilitators as well as the participants to the workshop to follow it and run the different experiments.

Mixed Pull Model

Q6. After having evaluate the Mixed Pull model, what do you think that the success factor in achieving the level of detail against the currently used model?

Answer:

- Layout – 100% of the current model
- Logic – due to the fact that is incomplete I will suggest around 70%

Q7. After having evaluated the Mixed Pull model, what do you think is the success factor in?

- Illustrating the Mixed Pull Principles?

Answer: I believe it is simulating the Mixed Pull principles since the Supermarket both pushes as well as pulls from the system. Although the model is not completed the majority of the expression language is there and therefore it seems to be just a matter of some extra time to be spent on it.

Q8. Which do you think are the strong points of the Push model?

Answer:

- Mimic the exact layout
- Fundamental elements are there and ready to run
- Correct routing

Q9. Which do you think are the weak points of the Mixed Pull model?

Answer: due to the fact that it is not completed I cannot comment on this point, but I strongly believe that there will be very big problems with it.

Q10. Is the Mixed Pull model user friendly? Is it useable for the training purposes you intent to use it?

Answer: For training reasons it seems to do whatever it supposes to. But in the user friendliness is somehow more complicated than the Push one. This is due to the fact that

much more factors have to be changed between experimental periods like reorder points, safety stock quantities etc.

V.S.M

Q11. What is the success of the library against your expectations? Is it complete?

Answer: 100% is exactly what was asked from you to do. There are all of the icons there ready to be used, and maybe more than what I thought.

Q12. Is the library user friendly?

Answer: Very much so. They are ready to be used; I managed already to make a small model by using them.

6.4.2 Mr. John Britton

Push Model

Q1. After having evaluate the Push model, what do you think that the success factor in achieving the level of detail against the currently used model?

Answer: I believe that the model mimic very successfully the current model used by our company in the regions of 90%. The structure of all the components is there and I am especially pleased with the assembly workstations since they are very easy to change their elements.

Q2. After having evaluated the Push model, what do you think is the success factor in?

1. Illustrating the Push Principles?
2. Illustrating the effects that the batch production has to the system?

Answer:

1. Yes, it is illustrating the Push principles 95% , very pleased with it
2. Yes 90%, it is strongly showing the effects of the batch production, especially with the inventory counter that you have put in the assembly station 3. Nevertheless, there is some space for potential improvement

Q3. Which do you think are the strong points of the Push model?

Answer:

- Mirror the first stage of the analysis so that to make the participants understand the effects
- Shows the very long lead times
- Large inventory levels

Q4. Which do you think are the weak points of the Push model?

Answer: I cannot see any weak points except the fact that could be stronger in the visual department. Maybe some animation, video clips etc.

Q5. Is the Push model user friendly? Is it useable for the training purposes you intent to use it?

Answer: It seems that is very easy to manage the changes between the experiment periods, it seems that there will be no problem with the participants to follow it

Mixed Pull Model

Q6. After having evaluate the Push model, what do you think that the success factor in achieving the level of detail against the currently used model?

Answer:

- Layout 100% completed and very accurate of the current model very pleased with it.
- Logic although not finished I will suggest in excess of 50%

Q7. After having evaluated the Mixed Pull model, what do you think is the success factor in?

- Illustrating the Mixed Pull Principles?

Answer: I believe that it very successfully is doing so, although I will not give a percentage since I have not seen it working properly since there are still elements to be validated.

Q8. Which do you think are the strong points of the Mixed Pull model?

Answer:

- The layout is completed and easy to follow as well as to change it
- The part of logic seems to be working although cannot judge it in its overall performance since not completed
- Demonstrates the effects as it is done to the Push one

Q9. Which do you think are the weak points of the Push model?

Answer: It is not completed

Q10. Is the Push model user friendly? Is it useable for the training purposes you intent to use it?

Answer: More complicated than the push but after familiarisation with it, it seems that there will be no major difficulties

V.S.M

Q11. What is the success of the library against your expectations? Is it complete?

Answer: 100% very pleased with it, everything is there

Q12. Is the library user friendly?

Answer: Cannot see any reason why not

6.4.3 Mr. Steve Allen

Push Model

Q1. After having evaluate the Push model, what do you think that the success factor in achieving the level of detail against the currently used model?

Answer: I believe that the model replicates in high degree of detail the current model used by the company in the region of 90%. The 10% that I have not accredited to the model is due to the fact that needs some tidying up in order to look more professional.

Q2. After having evaluated the Push model, what do you think is the success factor in?

3. Illustrating the Push Principles?
4. Illustrating the effects that the batch production has to the system?

Answer:

1. I believe that it does whatever it suppose to do, Push products through the system

Q3. Which do you think are the strong points of the Push model?

Answer:

- I believe that the routing is very detailed
- The assembly stations are very detailed, it should be avoided if model was not to be used for training reasons, but since it is for training reasons it is more than successful.

Q4. Which do you think are the weak points of the Push model?

Answer: Personally speaking by looking the model as a professional simulation programmer, I believe that they could be done in a more simply manner and not such

detail which can make the model to look and be more complicated. But based on the fact that no training was provided to the student I believe that it is as good as it could get.

Q5. Is the Push model user friendly? Is it useable for the training purposes you intent to use it?

Answer: Yes, it is quite simple to modify the inputs of the system since everything is happening through the linked tables of the spreadsheet.

Mixed Pull Model

Q6. After having evaluate the Mixed Pull model, what do you think that the success factor in achieving the level of detail against the currently used model?

Answer: The layout I believe is very detail 100%, the fact that there is the expression language in the gates but not in all of them I believe that in the logic 80% is there. But I believe that there might be some other issues that will surface after the completion of the programming, so some extra evaluation of the models might need to be done.

Q7. After having evaluated the Mixed Pull model, what do you think is the success factor in?

- Illustrating the Mixed Pull Principles?

Answer: I believe it very successfully Pulls and Pushes throughout the elements of the model. It is 100% successful based on the logic that was used when created. The limiting factor again is the non completion of it.

Q8. Which do you think are the strong points of the Mixed Pull model?

Answer:

- The accuracy of the model
- The detail of the layout
- The smarter logic and better use of expression language due to greater experience

Q9. Which do you think are the weak points of the Mixed Pull model?

Answer: Again as in the push model there are some elements of the model that could be done in a better manner. And of course the fact it is not finished and not fully evaluated.

Q10. Is the Mixed Pull model user friendly? Is it useable for the training purposes you intent to use it?

Answer: Less than the Push model, due to increased complexity in the logic of the Push and Pull. Some familiarisation with the model should prove enough.

V.S.M

Q11. What is the success of the library against your expectations? Is it complete?

Answer: N/A

Q12. Is the library user friendly?

Answer: N/A

6.4.4 Extra Comments for the Project

Except the previously detailed twelve questions all three interviewees were asked at the end of the interview to provide their opinion about how they think the project has been managed from the student as well as whether they want to add something more than just the answers to the questions. Mr. Peter Rice Mr. John Britton proposed to provide their comments in writing and email the document to the student. Mr. Steve Allen provided his comments in verbal.

6.4.4.a. Mr. Peter Rice & Mr. John Britton Comments

The complexity of the modelling techniques and the extent of the training required for the writing of expression language within Simprocess were seriously underestimated and with advanced training resources only being available towards the back-end of the project, that is why some of the tasks are only partially completed.

Student Approach:

Eugene has clearly put a good deal of effort in to this project and has spent many hours working through the complexity of the various models in Simprocess. He has been flexible in his approach and prepared to travel to various sites as required.

Eugene was able to understand the issues involved in both the lean and the simulation aspects of the project and we have found him capable of taking on board some of the more complex modelling & lean constructs throughout the project. Importantly he has remained open minded through some of the more difficult stages of the project – it would have been easy to give up.

In my opinion the partial completion of the project reflects more upon the underestimation of the level of modelling required, than his ability to manage the final stages of the project and I thank him for his efforts in completing this project for us. The complexity of the modelling techniques and the extent of the training required for the writing of expression language within Simprocess was seriously underestimated as it is

and with advanced training resources only being available towards the back-end of the project

Peter Rice
Director BRM³ Ltd

6.4.4.b. Mr. Steve Allen

The limited extend of the mixed pull model is due to the lack of training of the student. It should have been arranged for the students to participate in intensive simulation training course. There are courses to take you through the basic use of the Simprocess software and teach you more of its capabilities. "*Simprocess is more the tool of the professional*" and that is why the use of expression language is very big. It is a great tool to give you the correct answer, but it is of limiting animation capabilities. This is due to the belief of the developing company that is a tool for providing solutions and not nice pictures. The way that the expression language is used it is more mathematical than other software that I have use, but this is its strong point for providing better simulations.

6.5 Analysis of the Findings

The table below summarises the completion of the project from BRM3's perspective as from the feedback gathered from the conducted interviews and extra comments provided to the student from the three interviewees. It is apparent that not all aspects of the project have been fully achieved as envisaged within the original project brief which outlined four tasks:

1. Build a push, mixed pull simulation model based on the "simply lean" workshop
2. Create a library of Drag & drop icons for Value Stream mapping
3. Create re-useable templates for push, pull & mixed pull models
4. Evaluate the effectiveness of Simprocess

The following Table 3 will summarise the findings of the interviews in a quantitative form which is easier to follow than the words that they provided in the interviews. Also comments are included so as to justify the percentage score allocated in each of the tasks.

Table 3: Summary of the Findings from the interviews conducted

Task	Stage	% Completed	Comments
1) Model Build	a) Push	95%	Working effectively – some minor refinements and timing experiments can now be done over time. Working well.
	b) Mixed Pull	60%	Design finalised & Model Infrastructure built – some expression language needs copying for total completion. Can be done in time.
2) Detail & Accuracy of models	a) Push	100%	All the detail of the operations included in the physical model is there and working as appropriate
	b) Mixed Pull	95%	Although incomplete the detail and the accuracy of the model can be evaluated and is seen as very successful
3) Success of the Training Purpose of the Models	a) Push	100%	Very successfully shows the effects of the batch production in the system
	b) Mixed Pull	N/A	Due to the incomplete nature of the model is difficult to put a percentage score at this point. Although all the interviewees are very optimistic and suggest that it will work very well as a training tool as it is based in the correct logic, and there is nothing fundamentally wrong.
4) V.S.M Icons		100%	Completed and tested.
5) Lean Templates		60%	Will combine with the Lean Icons once all two models are completed.
6) Simprocess Evaluation		90%	Able to evaluate Simprocess through the Push model and the partially finished Mixed Pull model.

As it can be seen from the previous Table 3, the task 1 as an overall success of the building the electronic form of the Simply Lean workshop was rather successful if considering the lack of training that was provided to the researcher for the simulation software. The four elements of the package are completed in a high percentage, despite the fact that the second model is not completely finished. Although the problems that

were appeared during the project execution, the sponsoring company is quite satisfied with the outcome, since it allowed them to see the truth about the workshop that they currently use.

The information gathered for the accuracy as well as the detail of the two models in correspondence to the currently used "Simply Lean" model, was also very successful. There is an overall 97% accuracy and detail between the models, which clearly shows that although the mixed pull model is not totally finished the people from the sponsoring company, who have seen the models running as well as the detail in each one of them are very pleased with the way that they have been created. Of course, Mr. Steve Allen as a simulation expert, pointed out that there is an easier way of constructing the models, than the one that the researcher used. He pointed out that the easier way that he suggests is due to his familiarity with the software as well as the experience he has gained by being a simulation professional for the last almost 20 years.

The most successful part of the electronic form of the "Simply Lean" workshop is the V.S.M Icon Library, and as it can be seen there is a score of 100%. Also Mr. Peter Rice has added to his comments that the *"creation of drag and drop V.S.M Icons is complete and has been tested satisfactorily. Once all models are completed this can be combined with the various processes within the models to complete the Lean Templates."* So as it can be seen from the comments provided the way that the library was constructed as well as the completeness of the Icons used to construct the library is something that the sponsoring company is very pleased with.

Also the fact that the models are functioning as they anticipated, gives them the indication that there are many benefits to be gained from the further investigation of the use of the Simprocess software as part of the workshop. As Mr. John Britton said during his interview he was anticipating that the project will not be completed 100% due to the problems with the training as well as the amount of things to be done. However, as he commented he is very satisfied with the amount of the project completed and all the hard work is been done and the remaining work is just the fine tuning of the mixed pull model.

The lean templates that the sponsoring company wanted to create, have been created although the score is quite low just 60%, but this is due to the incomplete mixed pull model. The mixed pull system model can be built upon at a later date to complete the picture of a lean transformation, but for the purposes of demonstrating whether computer simulation can assist simulation-based learning exercises, the project has achieved its objective.

Also the last task of the project was the Simprocess evaluation as software to be used in order to provide a training tool/aid for the Simply Lean workshop. Despite the fact that the mixed pull is incomplete, the tasks which have been completed, enable us to draw favourable conclusions as to the effectiveness of Simprocess as a training tool within

Simply Lean and the Push System Model will add a new dimension of complexity within the discovery learning of the workshops.

6.6 Summary

Summarising this chapter of the report it can be said that the objectives for this part of the project have been totally achieved. By saying so the researcher wants to make clear that the complete evaluation of the electronic form of the “Simply Lean” workshop is completed and the feedback gathered from the sponsoring company is very good. This happened due to the very thorough research in the interviewing techniques as well as the best medium to be used in order to be more successful. The factors of the time limitations as well as the distance, and low cost drove the researcher to use a telephone survey interviewing technique as the most efficient for this situation.

Also to the success of the interviews added the research for the design of questionnaires something that allowed the researcher and made it easier for him to justify the design as well as the questions finally used to gather the feedback. Also the help from the interviewees that express their true opinions about the outcomes of the project was also another important factor that contributed to the success of the interviews.

7 Discussions and Conclusions

At this point of the report the researcher is ready after having gather feedback for his work as well as having the project behind him to draw conclusion for the findings as well as the problems faced, the limitations and make recommendations. Also at the end he will be able after having seen the overall picture of the project to make recommendations for future work to be undertaken.

7.1 Conclusion of Findings

As this project is completed the researcher wishes to reflect in the work done and what is the significance of it for the success of the project. The project was taken from an idea that BRM³ had to combine the use lean training with the use of simulation software after having seen that the physical simulation has many limitations. Also they wanted to combine simulation software with the V.S.M Icons so that it will be easier for the participants at the workshops to follow the models. So the research student was called to create the infrastructure of this “new” electronic form of the “Simply Lean” workshop.

In order this to be done the project had to be broken down into smaller elements which were easier to manage as well as easier to understand. So the project while having an aim, the student had to identify the objectives that need to meet in order to achieve the overall aim. These objectives were made clear and after consideration were divided into two main stages; each of these stages will have several smaller steps. So the first stage was to create the entire infrastructure for this “new” workshop. To do that the researcher decided that the Push model had to be constructed first, since it is easier, due to more simple nature of the subject compared to the mixed pull model. At that point it was believed that this activity will give enough familiarisation to the researcher with the program, in order to tackle the more demanding model of the mixed pull as well.

The Push model was built but with far greater time spent on it than what was anticipated, due to lack of training which was promised but did not materialised, that delayed the project very much. When the push model was finally completed and all its detail elements were inputted, the researcher had to start building the mixed pull model. The mixed pull model was far more demanding in terms of expression language; the logic behind the model was far more complicated since the same model had to be made to pull as well as push in its elements. It was requiring a supermarket with 29 buffers in it. That made the building of the model very time consuming, and finally the researcher did not had enough time to finish it.

After the modelling part of the project has been completed the creation of a V.S.M Icon Library had to be created so that to be used in conjunction with the push and mixed pull models and create a better training tool. The creation of this library was very successful, and when tested from the sponsoring company, only positive feedback was gathered.

The next stage for the completion of the project was the evaluation of the models from the company as well as the V.S.M Library. Also the researcher of this project had to be able to gather feedback to evaluate the Simprocess software in order to decide whether it is suitable for assisting training as well as act as an implementation guide for lean six sigma. The feedback gathered for this matter, from the sponsoring company was rather positive. Although the mixed pull model was not completed, the sponsoring company after evaluating the models and especially the completed push model they decided that it is very visual which will assist them in the training. The fact that the consistency in the detail was very high throughout the building of the models it helped them to understand that even though the mixed pull model in not completed the foundations are there and it is just a matter of some extra work to be done on it.

Finally after the final stage of the project was completed the researcher was able to gather all the information needed in order to evaluate the project. The use of Simprocess is very good for training reasons although it was pointed out from the simulation expert Mr Steve Allen that the Simprocess software is not very strong in the animation sector, but it is very good in finding the correct solutions. The company is very satisfied for the purposes that they want to use it for. Also it is possible to use the V.S.M icons library to make the models easier for the industrialists to understand them.

7.2 Limitations

The only limitation with the project was the fact that the company was not able at the start of the project to supply adequate training as it was promised to the researcher. Simprocess is a software package that the researcher was not familiar with, something that was clear from the beginning, and that was the reason that the company had to provide training. At the beginning the only help that the researcher had was the user manual of the software which was adequate help for the stage of the familiarisation with the software which all in all happened quite successfully, but more obstacles surfaced when the model had to pass from the simply conformation with the layout and pass to the major objective of simulating Push and Mixed Pull. The need for importing all of the expression language as well as making sure that the routes were kept precise added up to the complexity of the model. At that point the use of the available resources, user manual for the software, were not adequate which drove the project at a stand still for almost a month. External help came finally from the company, by hiring a specialist to help create the mixed pull model but unfortunately this happened only a couple of weeks before the completion of the project. The drawback of this was the inability to complete the mixed pull model. As both Mr. Peter Rice and Mr. John Britton kindly admit is that the issue of training was underestimated from the beginning due to the fact of the underestimation of the complexity of the models.

The complexity of the model was somehow hidden, since as models in paper they seem quite simplistic as well as not very demanding from a computational point of view. The

inexperience of the researcher of this project did not allow him to identify the pitfalls in the very early days of the project. As was later said from the specialist in simulation Mr Steve Allen the Simprocess software is the tool of a professional since it requires very good knowledge of the expression language in order to allow the software to perform at its top capabilities. When you get the hold of the expression language everything is much easier to run.

7.3 Future work to be undertaken

As the project has been completed and the conclusions have been drawn the researcher wishes at this point to make recommendations for future work to be undertaken. Of course the first thing to be done will be the completion of the mixed pull model expression language within the supermarket process and model output table to mimic the outputs from the simulation workshops.

After this has been completed then the next step to be taken will be the evaluation of the mixed pull model in all its elements since so far it has been done only in the elements before the supermarket as well as the supermarket itself. After this procedure has been completed the tidiness of both the models can be easily achieved.

The researcher believes that this specific project can form the foundations of many interesting projects to be done after it. The introduction of the electronic form of the Simply Lean can be done in the workshops, and from therefore the models to be used as they intended to.

Also the use of these models under a secure server with the ability to perform teaching through the internet is another possibility to happen. The fact that the models are very flexible in their formation gives them the advantage that they can easily be changed and so on everybody will be able to use them, for teaching purposes.

Also the creation of the Icons that consists the V.S.M Library, that will perform as actual process boxes will be a very big step forward for the software as well as for training reasons. The process characteristics could be embedded within the Icons so that the impact of the varying the coefficients of variance within processes can be measured which will increase the appealing of the software.

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APPENDIX 1

Article: Cochran, Z. Zhao and Q. Ng, "*The Role of Physical Simulation in the Re Design of Existing Manufacturing Systems*", Production System Design Lab, Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA, USA.

The Role of Physical Simulation in the Re-Design of Existing Manufacturing Systems

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Abstract

Currently there are a number of computational and physical tools available to engineers/managers to model and simulate a manufacturing system. However, for a successful implementation, the manufacturing team members need to be successfully educated about the changes to their working environment and the underlying rationale for change. The Production System Design Laboratory at MIT developed a physical modeling process aimed directly at re-designing existing manufacturing systems and educating shop floor workers for the successful implementation of a new system. Creating a physical model of the material and information flow within a manufacturing system promotes visualization of a system's design and operation. It eliminates the ambiguity in defining the system design. The physical simulation provides a powerful educational and training tool that stimulates learning and improvement by all team members involved with its operation and design. This paper presents a methodology to re-design an existing manufacturing system based on implementation experience and illustrates the role and use of physical simulation in the manufacturing system re-design process.

Keywords: Manufacturing, System, Design

1 INTRODUCTION TO PHYSICAL SIMULATION IN MANUFACTURING SYSTEMS

As part of a holistic approach to creating and implementing a manufacturing system design, physical simulation is a tool that enables all stakeholders to interact with and to design a manufacturing system in a cost and time-efficient manner. Its use provides the ability for system designers to focus on how the work is done; it also enables the physical expression of a Value Stream Map (VSM)[1]. By putting the work into motion and expressing the content of a value stream map physically, the ambiguities associated with manufacturing system design and operation are all but eliminated. Once the physical simulation model of a manufacturing system's value stream is built, it may then be used for education, training and improvement activities. This paper presents a process that uses physical simulation as part of a methodology to re-design existing manufacturing systems. The process presented was born from the re-design of several value streams within a unionized automotive components plant operating in the U.S.A.

The term *physical simulation* as used herein describes the creation of a scale model of a manufacturing system's material and information flow, operational practices and standardized work activities to operate a manufacturing system. It may be used as a visualization and design tool to unambiguously define a system's design and operation. Physical simulation may be used to promote true learning. The key to promoting true learning is to first challenge the team members to understand the objectives of a manufacturing system's design and then to be able to associate the physical implementation of the system design to the achievement of the manufacturing system's objectives.

2 CREATING AND IMPLEMENTING SUCCESSFUL CHANGE WITHIN A MANUFACTURING SYSTEM.

Physical simulation may be applied to the re-design of existing manufacturing systems. Figure 1 provides a flowchart of the process for re-designing existing manufacturing systems. A manufacturing system can be defined as the following: "the arrangement and operation

of machines, tools, materials, people and information to produce a value-added physical, informational or service product whose success and cost is characterized by measurable parameters [2][3]. Below is a description of the manufacturing system re-design process steps outlined in Figure 1.

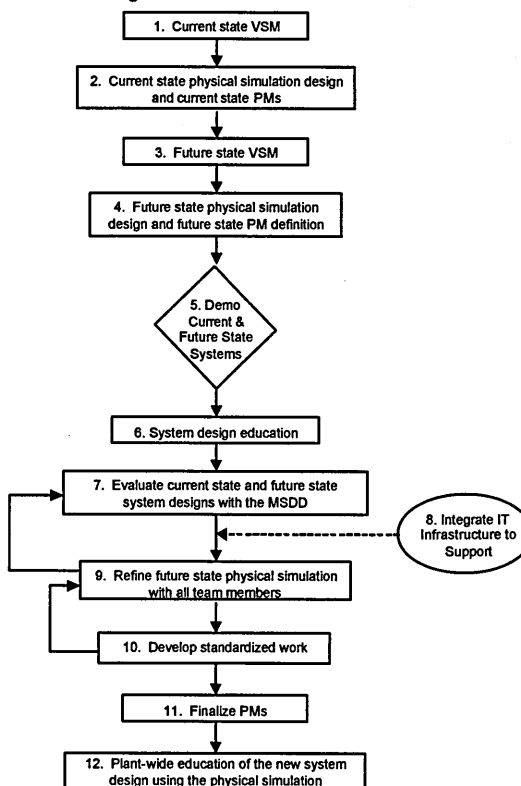


Figure 1. Flowchart of Change Process to Design and Implement a New Manufacturing System

1. Current state Value Stream Map (VSM). Establish the value stream map of the current state manufacturing system. Depict the material and information flows in the system.
2. Current state physical simulation design and current state Performance Measures (PMs). Develop a current state physical simulation based upon the existing manufacturing system's design and operating practices. The physical simulation should be a simplified, scale model of an existing value stream within a plant. This step should also capture how the existing system is measured and model the behaviour of the people within the system resulting from the existing PMs. The current state physical simulation model provides the basis for people to learn, observe and to initiate change.
3. Future state VSM. Establish the future state value stream map. The material and information flow for the future state value stream should be designed so that the objectives of a *stable* manufacturing system are achieved. [4]. A stable manufacturing system design achieves the objectives of manufacturing system stability to produce the right quantity, right mix with perfect quality to customer in spite of variation. When a problem condition occurs, the system design must indicate immediately the problem condition.
4. Future state physical simulation design and future state PM definition. Design the future state physical simulation in alignment with the future state VSM that schematically illustrates the design to achieve system stability. Concurrently, new performance measures should be established for the new manufacturing system. The performance measures should reward the achievement and improvement in the achievement of the system stability objectives of producing the right quantity, right mix with perfect quality to the customer.
5. Physical simulation demonstration of the current state versus the future state. This demonstration is the "gotcha" event. It is the learning milestone. The demonstration contrasts the operation of the current state system with focus on contrasting the role of people in a stable and an unstable manufacturing system. There is a sharp contrast in the roles of people in operating the stable versus the unstable system. In an unstable system, the people's best efforts barely keep the system alive. The focus is on trying to ship parts, sometimes any part. In contrast, the new system design enables a focused problem identification and improvement process. The people work on improving the work itself and not on merely shipping parts out the door [5]. The simulation illustrates the opportunity cost of people not working on improvement. It captures the hearts and minds of the people in the system, since they are able to see (sometimes for the first time) that their manufacturing system can be truly successful, but only if it is *designed* to achieve the objectives of a stable manufacturing system.
6. System design education. This step follows the "gotcha" milestone. Educational workshops cement the learning. During these workshops the participants learn how to design a manufacturing system to achieve the system stability objectives. The participants also learn how to design systems to achieve the objectives (FRs) and means (DPs) as decomposed by the Manufacturing System Design Decomposition (MSDD). [6]. These workshops also present case-study research results and the specifics for designing manufacturing systems [7].
7. Evaluate current state and future state system designs with the MSDD. This step ensures that the weaknesses of the existing and new system designs are identified clearly. A questionnaire has been developed to evaluate the current state and future state manufacturing system designs [8][2]. The questionnaire evaluates how well the FR-DP pairs identified by the MSDD are actually achieved by the system design. Every member of the system design team may complete the questionnaire. The MSDD is a complementary tool to VSM. The MSDD defines the objectives and means that a system design must achieve holistically. It decomposes the objectives and means within a system design to improve quality, decrease delivery response time and to improve delivery reliability. It also states the objectives and means that reduces the root causes of operational cost. The MSDD compliments VSM. VSM identifies the material and information flow necessary to achieve the objectives and means stated by the MSDD.
8. Integrate IT infrastructure to support system objectives. A benefit of constructing the physical simulation model is that the use of the supporting information technology may also be physically simulated. This step requires the live and concurrent operation of the information technology with manufacturing. The physical simulation establishes a laboratory environment in which all of the important interfaces are exposed and tested. An important aspect of this integration is to enable all participants to agree on one model for the design and operation of the manufacturing system. The participants learn how their business practices affect manufacturing and, significantly, are able to re-design their business processes to effectively meet the objectives of the manufacturing system. In fact, the participants learn that they are indeed part of the manufacturing system and learn the impact of their decisions on the design and operation of the manufacturing system.
9. Refine future state physical simulation with all team members. The simulation requires multiple iterations of refinement to ensure success. All team members are asked to run the physical simulation (concurrently with the IT support). Each team member tries to make the simulation fail and asks "what if" questions. The purpose of the step is to make the work methods in the simulation as realistic as possible and to improve the system design's robustness in addressing problem conditions.
10. Develop standardized work. Standardized work defines the work methods necessary to operate the manufacturing system. Standardized work affects the work of both salaried and hourly team members. In fact, standardized work defines how management will react to specific problem conditions. Developing standardized work is crucial to the successful launch of the new manufacturing system. The people who operate the new system must know *what* to do and *why* they are doing it. The standardized work helps to answer these questions for the operating personnel. The physical simulation enables the participants to test the standardized work methods. The standardized work methods must be written down. Significant changes to the written standardized work instructions will be made as a result of testing the standardized work methods with the physical simulation. Finalize performance measures (PMs). This step ensures that the PMs that are used to evaluate the new system's performance are

aligned with the objectives of the new system design. It can be disastrous to operate a new system design and yet measure its behaviour based on an inappropriate set of performance measures. In fact, many systems evolve into physical designs based upon the way they are measured. Plant-wide education of the new system design using the physical simulation. Once the simulation has been designed, tested and the standardized work developed, the physical simulation may be used as a powerful teaching and educational tool. This step captures the idea that everyone in the re-designed manufacturing system may be taught the new system design using the physical simulation.

3 INTRODUCTION TO DESIGNING A PULL MANUFACTURING SYSTEM

Pull is a name for a type of material and information system design [9]. Within a pull system, information flows in the reverse direction of the material, which is contrary to push systems where information and materials flow in the same direction [10].

In the presence of operational variation as evidenced by conditions such as *fall out*, in which a percentage of the parts produced are defective (for example, an assembly or a paint operation), pull is used as a *countermeasure* [11]. Pull is a physical implementation of the means, called a countermeasure, to achieve the manufacturing system stability objectives in spite of operational variation. System stability is defined as producing the right mix and right quantity of parts based on customer consumption in spite of variation (or fall out) at the individual operations (i.e., paint or assembly). Pull enables customer demand information to be fed back to the upstream operations so that the system design compensates for variation at the individual operations. The system design objectives are met, in spite of problems at the individual operations.

Physically, pull is implemented through the introduction of an establishing a Standard Work In Process (SWIP) [10] inventory quantity between operations like paint and assembly. This SWIP is sometimes called a marketplace [1]. The SWIP acts to decouple the variation within operations from subsequent downstream operations. When assembly needs a part, a part is removed from the SWIP after the paint operation (assume that assembly follows paint). The goal of the paint production is to produce until its output SWIP is full. The pull and replenishment operations between paint and assembly create a type of feedback control mechanism. This mechanism is sufficiently robust to handle fallout (defective part manufacture) and other sources of variation.

The purpose of the SWIP inventory is to ensure the stability objectives of the manufacturing system are achieved in spite of the variation unique to individual operations. The greater the variation at the operation level, the greater the SWIP must be. System stability must first be established as a result of the manufacturing system design. Once stability has been achieved, the inventory (i.e., the pre-defined SWIP level) may be reduced as the sources of variation that caused the SWIP to exist in the first place are reduced.

The converse is true. The SWIP may be reduced to expose the sources of variation (waste) and therefore, cost, that exists within the manufacturing system [12]. True cost cannot be reduced by eliminating the piece-part contributors of cost through the indiscriminate application of cost reduction targets [5]. Improving the *work* and the *processes* that support the work in manufacturing reduces true cost.

The use of a system design to achieve system stability is a requisite first step to reducing cost. The system design can also expose waste or variation. It can provide a standardized method of problem identification and problem resolution to eliminate the variation or waste, and, therefore, true cost in the manufacturing system. Working on improving the numbers (the PMs) does not reduce cost; working on the work itself in manufacturing and improving the effectiveness of the manufacturing system in meeting its system stability objectives can only reduce cost. The key point for a successful *pull* system design is that all people in the system must have this understanding that the system design is the means to reducing total cost.

It is not enough to just show the team members and the engineers a value stream map. In a pull system, people on the shop floor should know the information and material flow for the entire value stream. As part of Prof. Cochran's methodology to redesign an existing manufacturing system in alignment with the enterprise objectives, physical simulation is one tool in the manufacturing system re-design process that can be used by all team members to visualize the design.

4 PHYSICAL SIMULATION DESIGN AND IMPLEMENTATION

The following section gives general guidance for designing and implementing a physical simulation for an actual manufacturing system.

(1) *Providing detailed working instructions for each operator.*

It is critical to develop detailed instructions to define the work content in the simulation. Since people participating in the simulation system come from all levels within the manufacturing system (management, engineering and shop floor), most of them are not familiar with the detailed operations at the workstations; and, after the scaling and simplifying, the simulation system's appearance varies greatly from the real system. Therefore, it is needed to give clear and detailed work instructions for each participant in the simulation to ensure participants clearly understand the work content and the procedures of operation at each workstation. Clear, well-organized working instructions will enable the simulation to be carried out smoothly, especially in the case when participants are not familiar with the actual manufacturing system. This point applies to steps 2, 4, 5, 9, and 11 in the system design flowchart (Figure 1).

(2) *Simulation system design.*

The physical simulation should be designed to reflect the material and information flow as defined by the current and future state value stream maps. The layout of the physical simulation does not need to reflect the exact physical layout of the plant. For example, the simulation workstations can be laid out in a small line from raw material inventory, to machining, to assembly and then to pack out and shipping even though the plant is not laid out in the same physical way. The important point is that the physical simulation closely models the material and information flow relationships.

A physical simulation enables people to see the information and material flow relationships in the manufacturing system as clearly as possible. This point applies to steps 2, 4, 5, 6 and 7 of the flowchart (Figure 1).

Both time and space need to be scaled from the actual manufacturing system down to a level that enables all participants to witness all of the stages in the system. By scaling the time and distance parameters, the simulation

models the physical parameters of the actual manufacturing system.

The other important issue that should be considered is the simulation of the variation within the manufacturing system. Variation is the root reason for most of the problems that occur in a manufacturing system. One of the main purposes of the physical simulation is to show people what types of variation occur within the manufacturing operations, and how this variation affects the stability of the system.

For a typical machining-assembly system, the most common variation comes from machine down time, incoming material defects and final product defects. In a real situation, these variations occur randomly and naturally; in a simulation, the system must be consistent with this randomness. The usual method used to achieve this purpose is to apply probability-generating tools, such as die or poker chips. For example, operators in a simulation can roll a die to decide whether a final assemble is defective or not.

In a physical simulation, it would be convenient to use some kind of general purpose working objects to work with, to substitute the products that are actually being produced. Lego is used for most of the simulations designed by the PSD lab. The reasons for using Lego as the working object are the following: (a) Lego of different colors and shapes can be easily used to represent different parts. Participants, who may not be familiar with the production process of the real product, are able to easily understand the assembly of Lego blocks. (b) As Lego assembly and disassembly processes are relatively standard operations, it is easy for designers to increase or decrease the complexity of the operation by adding or reducing the quantity of Lego blocks to be assembled. It is also very clear for people to see the different sub-assemblies in different workstations. (c) Lego blocks can be easily transferred in trays between different workstations in the physical simulation. (d) Lego can be easily procured and does not need any modification before being incorporated into a physical simulation.

(3) Carrying out the simulation in a manner of continuous improvement.

Even people who are familiar with the manufacturing system can get confused the first time they participate in a physical simulation. After 2 or 3 rounds, people can understand what is happening in the simulated system as the relationships between the simulated system and the actual system become more apparent. The physical simulation provides participants with clarity and an abiding respect for the objectives of the manufacturing system and its embodiment in the physical simulation. This point applies to steps 6, 7 and 11 in system design flowchart.

(4) The simulation and Manufacturing System Objectives.

The simulation becomes meaningless if participants focus on understanding the detailed operations at each individual workstation. An effective approach we at the PSD lab have found to encourage people to think systematically is to use objectives to orient the simulation. This is in accordance with the system design steps 7 and 11. At the beginning of each round of simulation, several important system objectives are announced, such as meeting customers' demands at the right time, in the right mix and with perfect quality. After each round, questions according to these objectives are asked, such as "Did we meet the customers' needs?" "What kinds of variation prevented us from achieving the manufacturing system objectives? Such questions can greatly help to focus peoples' attention on the system design. By answering

these objectives-oriented questions, people can contrast the current state and future state system designs.

5 APPLICATION OF PHYSICAL SIMULATION IN AUTOMOTIVE PARTS MANUFACTURING PLANT

The following section describes a physical simulation design/implementation carried out by PSD lab in an automobile part plant. One of the major products of this plant is a plastic bumper for different types of cars. The plant intends to implement a pull production system in their existing bumper production system by using Kanban to control information flow. PSD lab designed the new system according to the MSDD framework [2]. However, in order to implement the new design successfully, it is essential that all stakeholders involved with bumper production have a detailed knowledge of the production system and its dynamics. In other words, they need to see the value streams of the incoming pull system. Under this situation, a physical simulation was designed and carried out in the plant, all participants had the opportunity to take part in the simulation and the physical simulation greatly helped the understanding and implementation of the new system. The simulation was a deemed a success for this reason.

5.1 Introduction of basic production processes of bumper production area.

The basic processes of bumper production include injection molding, painting, assembly and pack out. Plastic bumpers are first formulated by injection molding plastic pellets into parts. An AS/RS transfer the injection-molded bumpers to storage. It then sends different types of bumpers to the painting booth. After being painted, the bumpers are sent back to the AS/RS again by AGVs. The assembly area's production schedule then requests the AS/RS to send bumpers of a particular type and color to the assembly area, where finally assembly and pack out for customers occurs. Figure 2 gives provides a layout diagram of the bumper production area.

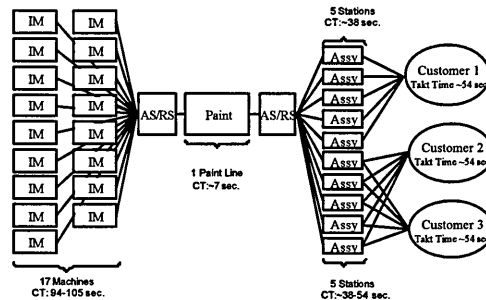


Figure 2: Diagram for physical layout of bumper production area

5.2 System design – current state and future state

The current production approach of the bumper area is characterized as "push" system. All working processes, including injection molding, painting, assembly, as well as AS/RS, are controlled by an MRP based production control system. Figure 3 shows the VSM of the initial, current-state system design.

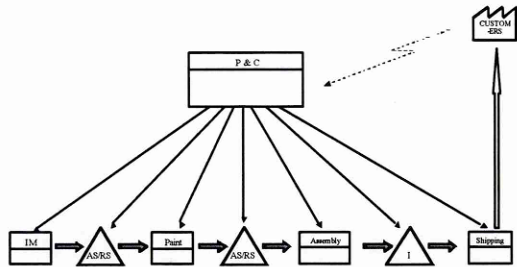


Figure 3: Current state value stream map

The current system's major problem is its inability to produce the right quantity and right mix of products according to customer demand. As the production is unstable and unpredictable, does not operate according to a balanced operating pattern and is controlled by demand forecast rather than by actual customer need, considerable inventory needs to be stored in the AS/RS to absorb these instabilities. As more and more customers of this plant change from large-run size batch-production to short run sizes as evidenced by In-line-vehicle-sequence (ILVS) production, the variation in the types and colors of bumpers has increased dramatically. The push system was unable to meet most of the demands from the customer on time. It was necessary to change from a "push" to a "pull" system as a countermeasure to accommodate the instability of the individual operations and to provide a basis for improvement and long-term cost reduction.

Figure 4 shows the future state pull system of the bumper production value stream. Customers' needs pull production via a production-leveling schedule. From the value stream it can be seen that the information flow starts from assembly, then travels back to painting, and finally to injection molding, through the kanban circulation system.

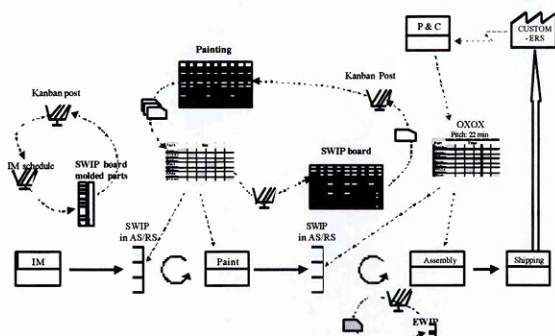


Figure 4: Future state value stream map

5.3 Physical simulation design

Parameter scaling for simulation

There are no preset rules for the simulation parameter scaling calculation. It is very case specific and should be decided according to the actual system to be simulated. Usually it is desired to finish one round of simulation in less than 15 mins, and this time period often stands for 1 shift (8 hours). After setting the simulation time, the designers of the simulation can decide the workload (how many parts to be built in this time period) and time allocation for each operation, according to the actual situation.

Simulation layout

The simulation layout does not need to be an actual replication of the factory floor. Instead, simulation workstations should be structured according to the value stream flow. The simulation designers set the time allocation of each operation.

Establish work instructions for operators in simulation.

Since not all people in the simulation are familiar with the operation details, it is very important to establish a clear and detailed standardized work instruction for every operator. The following is a typical standardized work instruction sheet for the painting operator. These instructions are revised, as the simulation is refined.

Work Instructions - Paint

- The cycle time in for the paint operation is 81 seconds
- Take 6 racks with molded parts and dump them into the large green box
- Determine the status of the painted parts according to the die scheme by rolling the dice
 - Put buff parts into buff bin
 - Put repair parts into repair bin
 - Put good parts into good bin
- Minimize number of partial bins
- Write down number of defects on "defect sheet"
- Bring good parts into AS/RS
- Bring buff parts and repair parts into rework area
- Take a break of 1.3 minutes during every shift

Number	Status
1	1x buff
2	1x repair
3	1x repair
4	good
5	good
6	good
6-6	all scrap

Fig 5: Example of a work instruction

5.4 Carry out the simulation

In carrying out the simulation, the simulation designers should be act as "supervisors," to observe the entire simulated system and to make sure all operators are following the working instructions. The simulation designers should be ready to answer any question that the participants may have.

After each round, the supervisor should make a concise summary and discuss with participants the simulated results. The discussion should focus on the problems that occurred in the simulation process, and should trigger suggestions for future improvement. Fig 6 shows a photo of a physical simulation carried out at an automotive manufacturing plant as part of the manufacturing system re-design process.

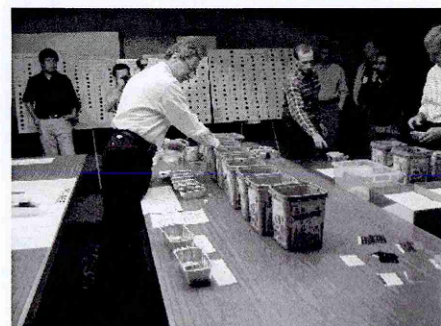


Fig 6: A physical simulation carried out at automotive manufacturing plant in the U.S.A.

6 SUMMARY

By scaling production parameters and substituting the real machines and working objects with people and Legos, physical simulation enables people to carry out "production simulation" in a relatively small space. Its main objective is to teach people to see the value streams of the whole system, and establish a systematic methodology to improve and redesign the existing manufacturing systems. The PSD lab of MIT designed several physical simulations for cooperating plants to help re-design their existing manufacturing systems and implement a new manufacturing system. The success of these physical simulations shows that it is a powerful tool in manufacturing system re-design and implementation.

7 ACKNOWLEDGEMENT

Although the physical simulation has appeared in many manufacturing companies and research institutes for a number of years, few of them have described academic research on the methodology for designing and implementing this valuable tool.

This paper is based on the pioneering work of the PSD lab of MIT. For the first time, an academic level study of incorporating physical simulation into the process of production system design was established. We want to thank Joachim Linck, Patrick Neise, and Jey Won for their valuable work, which contributes to the formation of this paper.

8 REFERENCES

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APPENDIX 2

{White}

```
Model.SUPERMAX := FLOAT(Model.SUPEREXB2MAX +
Model.SUPERMNB2MAX + Model.SUPERTTB2MAX +
Model.SUPERSMEDB2MAX + Model.SUPERSPFB2MAX +
Model.SUPERTPMB2MAX + Model.SUPERQFDB2MAX);
Model.WHITE := 10.0 + FLOAT(CEIL((Model.SUPERMAX/2.0) +
(Model.SUPERMAX/10.0)));
```

{Red}

```
Model.SUPERMAX := FLOAT(Model.SUPEREXB2MAX +
Model.SUPERMNB2MAX + Model.SUPERTTB2MAX +
Model.SUPERSMEDB2MAX + Model.SUPERSPFB2MAX +
Model.SUPERTPMB2MAX + Model.SUPERQFDB2MAX);
Model.RED := 10.0 + FLOAT(CEIL(Model.SUPERMAX/2.0));
```

{Green}

```
Model.SUPERMAX := FLOAT(Model.SUPEREXB2MAX +
Model.SUPERMNB2MAX + Model.SUPERTTB2MAX +
Model.SUPERSMEDB2MAX + Model.SUPERSPFB2MAX +
Model.SUPERTPMB2MAX + Model.SUPERQFDB2MAX);
Model.GREEN := 10.0 + FLOAT(CEIL(Model.SUPERMAX/2.0));
```

{Blue}

```
Model.SUPERMAX := FLOAT(Model.SUPEREXB2MAX +
Model.SUPERMNB2MAX + Model.SUPERSMEDB2MAX +
Model.SUPERSPFB2MAX + Model.SUPERQFDB2MAX);
Model.BLUE := 10.0 + FLOAT(CEIL(Model.SUPERMAX/2.0));
```

{Orange}

```
Model.SUPERMAX := FLOAT(Model.SUPERMNB2MAX +
Model.SUPERTTB2MAX + Model.SUPERTPMB2MAX +
Model.SUPERSPFB2MAX);
Model.ORANGE := 10.0 + FLOAT(CEIL(Model.SUPERMAX/2.0));
```

{Yellow}

```
Model.SUPERMAX := FLOAT(Model.SUPEREXB2MAX +
Model.SUPERTTB2MAX + Model.SUPERSMEDB2MAX +
Model.SUPERSPFB2MAX + Model.SUPERTPMB2MAX +
Model.SUPERQFDB2MAX);
Model.YELLOW := 10.0 + FLOAT(CEIL(Model.SUPERMAX/2.0));
```

{BB2}

Model.SUPERMAX := FLOAT(Model.SUPERMNB2MAX +
Model.SUPERSPFB2MAX);

Model.BB2 := FLOAT(CEIL(Model.SUPERMAX));

{BR2}

Model.SUPERMAX := FLOAT(Model.SUPEREXB2MAX +
Model.SUPERSMEDB2MAX + Model.SUPERQFDB2MAX);

Model.BB2 := FLOAT(CEIL(Model.SUPERMAX));

{BL2}

Model.SUPERMAX := FLOAT(Model.SUPERTTB2MAX +
Model.SUPERTPMB2MAX);

Model.BL2 := FLOAT(CEIL(Model.SUPERMAX));

{TABS}

Model.SUPERMAX := FLOAT(Model.SUPEREXB2MAX +
Model.SUPERMNB2MAX + Model.SUPERTTB2MAX +
Model.SUPERSMEDB2MAX + Model.SUPERSPFB2MAX +
Model.SUPERTPMB2MAX + Model.SUPERQFDB2MAX);

Model.TABS := FLOAT(CEIL(Model.SUPERMAX*4.0));

{LAMINATOR}

Model.SUPERMAX := FLOAT(Model.SUPEREXB2MAX +
Model.SUPERMNB2MAX + Model.SUPERTTB2MAX +
Model.SUPERSMEDB2MAX + Model.SUPERSPFB2MAX +
Model.SUPERTPMB2MAX + Model.SUPERQFDB2MAX);

Model.LAMINATOR := FLOAT(CEIL(Model.SUPERMAX/10.0));

Model.SPINES := CEIL(Model.EXB2N/10.0) + CEIL(Model.MNB2N/10.0) +

CEIL(Model.TTB2N/10.0) + CEIL(Model.SMEDB2N/10.0) +

CEIL(Model.SPFB2N/10.0) + CEIL(Model.QFDB2N/10.0) +

CEIL(Model.TPMB2N/10.0);

Model.COVERS := CEIL(Model.EXB2N/2.0) + CEIL(Model.MNB2N/2.0) +

CEIL(Model.TTB2N/2.0) + CEIL(Model.SMEDB2N/2.0) +

CEIL(Model.SPFB2N/2.0) + CEIL(Model.QFDB2N/2.0) +

CEIL(Model.TPMB2N/2.0);

Model.D[1] := FLOAT(Model.SUPEREXB2MAX + Model.SUPERMNB2MAX +

Model.SUPERTTB2MAX + Model.SUPERSMEDB2MAX +

Model.SUPERSPFB2MAX + Model.SUPERQFDB2MAX +

Model.SUPERTPMB2MAX);

APPENDIX 3

Model.D[2] := FLOAT(Model.SUPEREXB2MAX + Model.SUPERMNB2MAX +
Model.SUPERTTB2MAX + Model.SUPERSMEDB2MAX +
Model.SUPERSPFB2MAX + Model.SUPERTPMB2MAX);

Model.D[3] := FLOAT(Model.SUPERQFDB2MAX);

Model.D[4] := FLOAT(Model.SUPEREXB2MAX + Model.SUPERSMEDB2MAX);

Model.D[5] := FLOAT(Model.SUPERTTB2MAX + Model.SUPERSMEDB2MAX);

Model.D[6] := FLOAT(Model.SUPERSPFB2MAX + Model.SUPERTPMB2MAX);

Model.D[7] := FLOAT(Model.SUPERQFDB2MAX);

Model.D[8] := FLOAT(Model.SUPEREXB2MAX + Model.SUPERQFDB2MAX +
Model.SUPERTPMB2MAX);

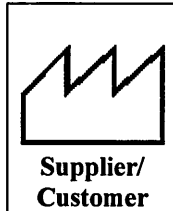
Model.D[9] := FLOAT(Model.SUPERMNB2MAX + Model.SUPERTTB2MAX);

Model.D[10] := FLOAT(Model.SUPERSMEDB2MAX + Model.SUPERSPFB2MAX);

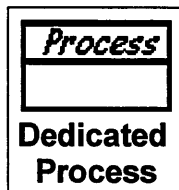
APPENDIX 4

VSM - Process Symbols

This icon represents both the Supplier and the Customer depending of its position in the Value Stream Map. When in the upper left, then it represents the Supplier since that is the usual starting point for material flow. When it is placed in the upper right, where the usual end point for the material flow then the customer is represented.



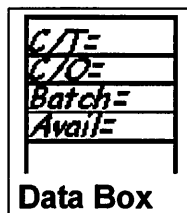
This icon it may represent a process, an operation, a machine or a department, through which material flows.



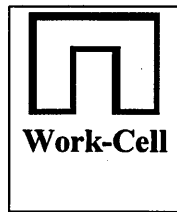
This is a process operation, department or work-centre that other value stream families share. That is why the difference in the shape of the process blocks.



This icon goes under other icons that have significant information/data required for analyzing and observing the system.

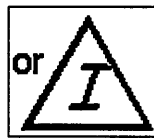


This following symbol is used when multiple processes are combined in a manufacturing work-cell. This kind of cells usually process, a limited family of similar products or a single product



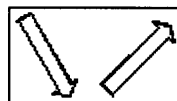
VSM – Material Symbols

The following icon is used to show the inventory that exist in-between two processes. This icon also represents storage for raw materials and finished goods.



Inventory

This icon represents the movement of raw materials from the supplier to the Goods In of a factory as well as the shipment of the Finished Goods from the warehouse of the factory to the customer.



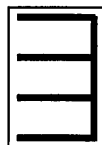
Shipments

The following symbol represents the pushing of the materials from one process to the next one.



Push Arrow

This symbol represents an inventory or supermarket, which is a small inventory, which is available and one or more downstream processes come to the supermarket to pick up what they need. The upstream processes then replenish the stocks to the required level.



Supermarket

The next symbol indicates the connection of the supermarket with the downstream processes which indicates physical removal.



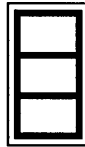
Material Pull

The First-In-First-Out inventory is used when the processes are connected with a FIFO system that limits the input. i.e. a roller conveyor



FIFO Lane

This icon represents an inventory or safety stock, used to prevent problems like downtime, and protect the system against sudden fluctuations in customer orders or system failures.



Safety Stock

This symbol is used to indicate the shipments from a supplier as well as shipments to a customer but by using external transport.



External Shipment

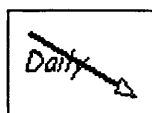
VSM – Information Symbols

This symbol is indicating a central production scheduling or control department or operation.



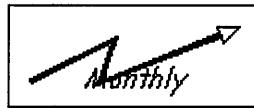
Production Control

This arrow shows the general flow of information from memos, reports, or conversation.



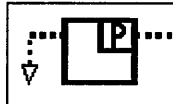
Manual Info

This arrow represents the electronic flow such as electronic data, Internet



Electronic Info

This icon is used to trigger production of a pre-defined number of parts. It is there to signal a supplying process to provide parts to a downstream process.



Production Kanban

This icon represents a card or device that instructs a material handler to transfer specified number of parts from a supermarket to the receiving process.



Withdrawal Kanban

This icon is used whenever the on-hand inventory levels in the supermarket between two processes drops to a trigger or minimum point.



Signal Kanban

A location where the Kanban signals are placed awaiting pickup. Often used with two-card systems to exchange withdrawal and production Kanban.



Kanban Post

This icon represents a pull system that gives instruction to a subassembly processes to produce a predetermined type and quantity of product, without using the supermarket.



Sequenced Pull

This icon is used in order to batch Kanbans, so that to level the production volume and mix, only for a period of time.



Haijunka Box

Scheduling using MRP/ERP or other centralized systems.



MRP/ERP

Gathering of information by the use of only visual means.



Go See

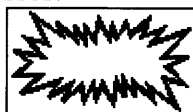
This icon represents verbal or personal information flow.



Verbal Information

VSM – General Symbols

This icon is used to highlight improvement needs as well as to plan the kaizen workshops for specific critical processes.



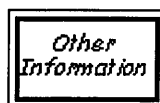
Kaizen Burst

This icon represents an operator. It shows the number of operators required to work at a specific workstation.



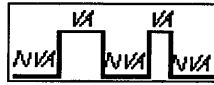
Operator

Other useful and or potentially useful information



Other

The timeline symbol shows the value adding times as well as the non-value adding times.



Timeline

Note: Information obtained from Rother. M., Shook. J., 1999, Version 1.2 "Learning to See – Value-Stream Mapping to create and eliminate muda", The Lean Enterprise Institute. Symbols have been drawn with the aid of Microsoft Visio Painter 2003.