Continuous flow design in a slow moving manufacturing environment

by

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Executive Summary

Aerosud is an established leader in the South African aviation industry and is an approved supplier of galley products for Airbus aircraft, since 2002. Aerosud provides aircraft systems and aeromechanical solutions for the local and international civil and military aviation industries. Their premises are adjacent to The Waterkloof Air Force Base near Pretoria.

The project will focus on the manufacturing of the Indigo Galleys, specifically the G1 type galley which is a standard type of galley. The galley assembly line is a slow moving manufacturing environment.

Aerosud is currently struggling to make profit on the galley assembly line. The assembly line currently produces galleys at a rate of 3.3 ship sets per month, where the total loss per month is R562 463. They are experiencing trouble with the productivity of the assembly line and this result in inconsistent lead times and increased costs. There is a huge variation in the time parts spend in the assembly line. Aerosud has limited records of the product flow of the galley assembly line. This makes it difficult to inspect the line and make improvements.

The aim of this project is to improve productivity. This in return will have a positive effect on profit and should create a continuous flow. The intended scope of this project will only cover activities directly related to the processes from the raw material to the customer in the galley assembly line.

The current operations have been analysed and future options developed by using Simulation Aided Value Stream Mapping. The operations causing the bottlenecks have been investigated and improved using various industrial engineering tools and techniques. Simulation modelling was used for evaluating improvement options in the bonding cell.

Two future state alternatives have been developed. By implementing the first alternative, the total profit per month would be R1434 528, but a major storage problem would be created. Alternative two would yield a total profit per month of R1260 534. The curing time reduction in the bonding cell will save R89 467.20 per year.

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1. Background and Introduction

1.1 Company Background

Aerosud is an established leader in the South African aviation industry. Aerosud Holdings was formed in 1990, and currently employs over 400 people. Aerosud provides aircraft components and aeromechanical solutions for the local and international civil and military aviation industries and has supplied more than 70 000 parts to Boeing during the past four years. Aerosud is divided into two manufacturing sections, which are engineering and interiors. Each of these sections is responsible for different products and designs. The engineering department mainly focuses on the outside of the aircraft, whilst the interior department is responsible for the inside of the aircraft. Aerosud premises are adjacent to the Waterkloof Air Force Base near Pretoria.

The company specializes in different production areas as follows:

- Vacuum Form parts and assembly
- Composite parts and assembly
- Board and Galley products
- Sheet Metal Parts
- Sheet Metal Assembly
- Electrical wiring and assembly

Aerosud became a Boeing approved supplier in 1998 to BQMS 9100, and in 2001 became a parts manufacturer for Boeing Commercial Airplanes, such as B737, B747 and B777. Although various products are produced, this project will only focus on the galley assembly line which forms part of the interior manufacturing section.

1.2 Project Introduction

Aerosud is an approved supplier of galley products for Airbus aircraft, since 2002. The project will focus on the manufacturing of the Indigo Galleys, specifically the G1 standard type of galley. The galley assembly line is a slow moving manufacturing environment. Galleys are designed and manufactured to a high customer specification, including standard fit requirements for trash compactor, full trolley refrigeration (flow-over), quick remove electrical boxes, wine chiller, etc.

Figure 1 G1 Galley

Raw material for the Galley is obtained from the stores, and cut to specification. After being cut bonding takes place to form the galley which also receives a plastic material overlay. The doors are mounted onto the galley and extra features according to customer specification are installed. Final finishing and inspection takes place followed by packing and transportation to finished goods stores. The assembly process of the galley line will be discussed in more detail in Section 11.1

2. Problem Statement (PLAN)

Aerosud is currently struggling to make profit on the galley assembly line. The assembly line currently produces galleys at a rate of 3.3 ship sets per month, where the total loss per month is R562 463. They are experiencing trouble with the productivity of the assembly line and this result in inconsistent lead times and increased costs. There is a huge variation in the time parts spend in the assembly line. Aerosud has limited records of the product flow of the galley assembly line. This makes it difficult to inspect the line and make improvements.

3. Project Aim

The aim of this project is to improve productivity. This in return will have a positive effect on profit and should create a continuous flow. To improve productivity all the factors tending to reduce productivity must be considered as well as the primary sources of waste in the process.

To help improve productivity, it is necessary to capture the current value of the assembly line as well as developing future value possibilities. This will be done by using value stream mapping (VSM) for creating value stream maps of the current and desired states of the assembly line. Value stream mapping (VSM) aids in the implementation of lean manufacturing and help to identify the value-added steps in a value stream, and eliminating the non-value added steps (waste). But despite its success, value stream mapping is a paper and pencil based technique which limits the level of detail and the number of different versions that can be handled.

To bridge the gap, simulation modelling will be used together with value stream mapping to develop a dynamic value stream. Simulation will be used to evaluate different options, support decisions and to develop future actions for the galley line.

In order to achieve an increase in profit and create continuous flow, the following objectives must be addressed:

- Understand the process and flow of events
- Document and visualize the current process
- Identify and map future flow possibilities
- Design and built the future state simulation model
- Collect and analyse the data of the current process
- Identify potential improvements to improve productivity
- Evaluate various improvement opportunities
- Identify the factors tending to reduce productivity and the primary sources of waste

4. Project Scope

The intended scope of this project will only cover activities directly related to the processes from the raw material to the customer in the galley assembly line. This includes the following:

- Raw material that is received from the stores
- All processes involved in converting the raw material to a finished product
- The packing of the finished product and the movement to finished goods storage

5. Project deliverables

- Current state value stream map
- Current state simulation model
- Future state value stream map
- Future state simulation model
- Factors tending to reduce productivity and the primary sources of waste
- Pareto charts with the primary causes of productivity reduction and waste
- Suggestions for improvements to enhance productivity and reduce waste

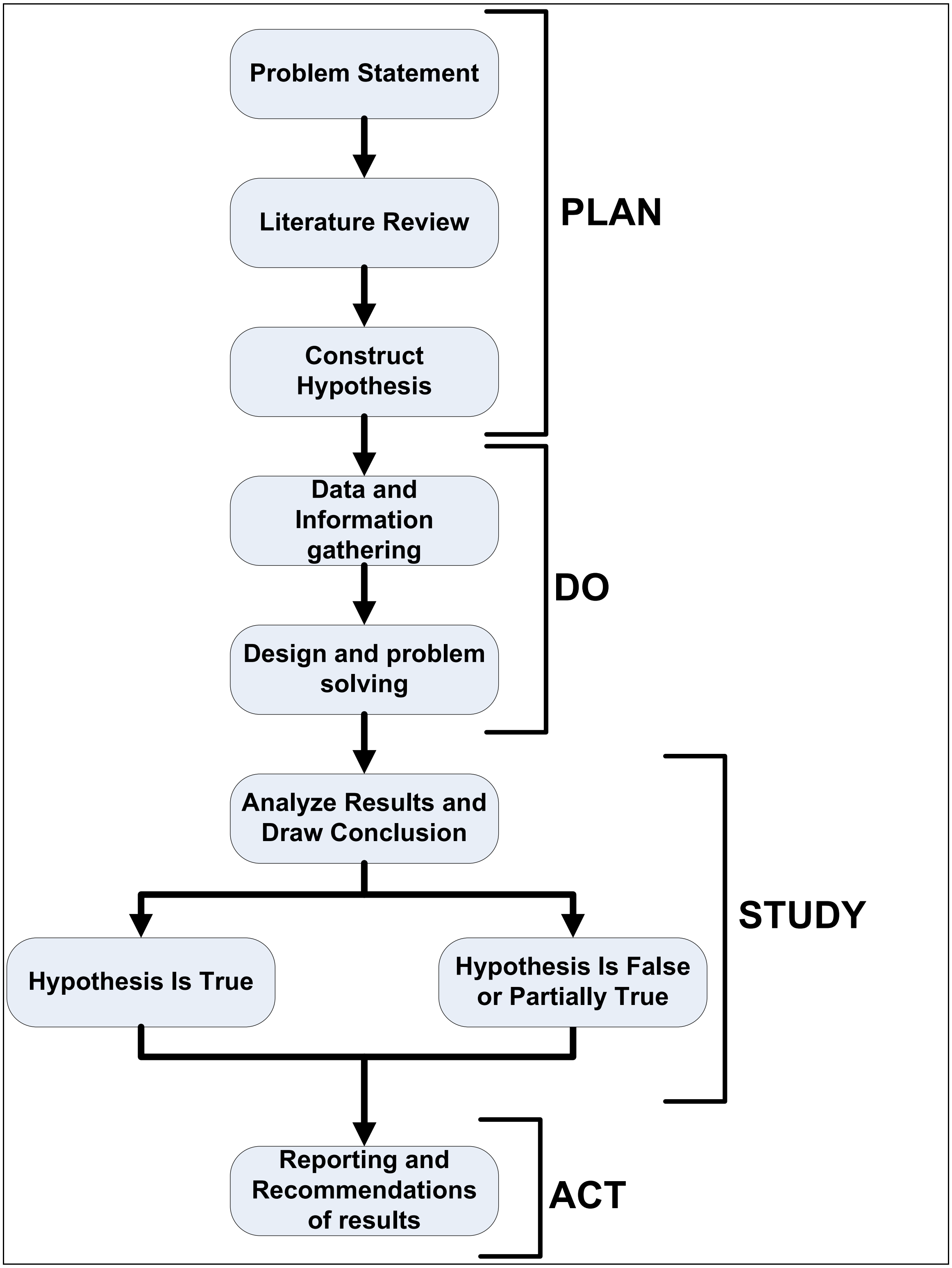
6. Project Approach

According to Gitlow et al (2005) the Deming (PDSA) cycle can aid management in improving and innovating processes, that is, in helping to reduce the difference between customers, needs and process performance. The Deming cycle consists of four stages: plan-do-study-act (PDSA).

The Deming cycle narrows the difference between process performance and customer needs and therefore the cycle will be used as the framework for the project approach. In order to assure the execution of the project all the project objectives can be grouped according to the Deming cycle. The logical sequence of the scientific method will be applied within the Deming cycle stages. The project approach can be viewed in Figure 3.

Figure 2 Deming Cycle (PDSA)

Figure 3 Project Approach



Stage one: Plan

- Identify the problem to be examined
- Formulate a specific problem statement to clearly define the problem
- Set measurable and attainable goals
- Brainstorm potential causes for the problem
- Investigate the opportunity to optimize the Value Stream Mapping Approach
- Identification and selection of the most appropriate Industrial Engineering methods, tools and techniques
- Formulate a hypothesis
- Verify or revise the original problem statement

Stage two: Do

- Divide the overall system into individual processes and map the process
- Use selected Industrial Engineering methods, tools and techniques
- Establish experimental success criteria
- Design experiment to test hypothesis

Stage three: Study (Check)

- Collect and analyze data to validate the root cause
- Gather/analyze data on the solution
- Validate hypothesis

Stage four: Act

- Report the findings
- Feasibility analysis of the various alternatives and recommendations

7. Resources

The following resources will be required to achieve the aim of the project:

- Mr. E Brett, Project Leader, Industrial Engineering Department, University of Pretoria
- Mr. F Nortje, Industrial Engineer, Aerosud
- Simulation software – Arena 7.01
- Internet access and textbooks for research
- Computer with Microsoft Office (Word, Excel, PowerPoint, Visio, Project)
- Transport

8. Literature Review

8.1 Overview

Prior to commencing with any project an Industrial Engineer is required to be informed about the most recent knowledge on processes, methods and techniques. This study presented an opportunity to obtain information from published materials, and apply the relevant knowledge to this project. The primary objective of this project is to improve productivity that in return will enhance flow in the production line.

Aerosud is currently struggling to make profit on the galley assembly line. They are experiencing trouble with the productivity of the line, which results in inconsistent lead times and increased costs. There is a huge variation in the time parts spend in the assembly line. Aerosud has limited records of the product flow of the galley assembly process which makes it difficult to inspect the line and make improvements.

More information on current operations of the assembly line was obtained by discussions with the workers and also observations by the student. Discussions with factory workers made it clear that the assembly line is struggling to produce the required output in the desired time. With the new contract awarded to Aerosud, the output rate for the assembly line must be increased by 20 galleys per year in order to meet the required demand. It was observed that there isn't continuous flow of products in the production line, but rather an unpredictable flow pattern caused mainly by the layout of the galley assembly line.

According to the International Labour Office (1979), productivity can be defined as nothing more than the arithmetical ratio between the amount produced and the amount of any resources used in the course of production. These resources may be:

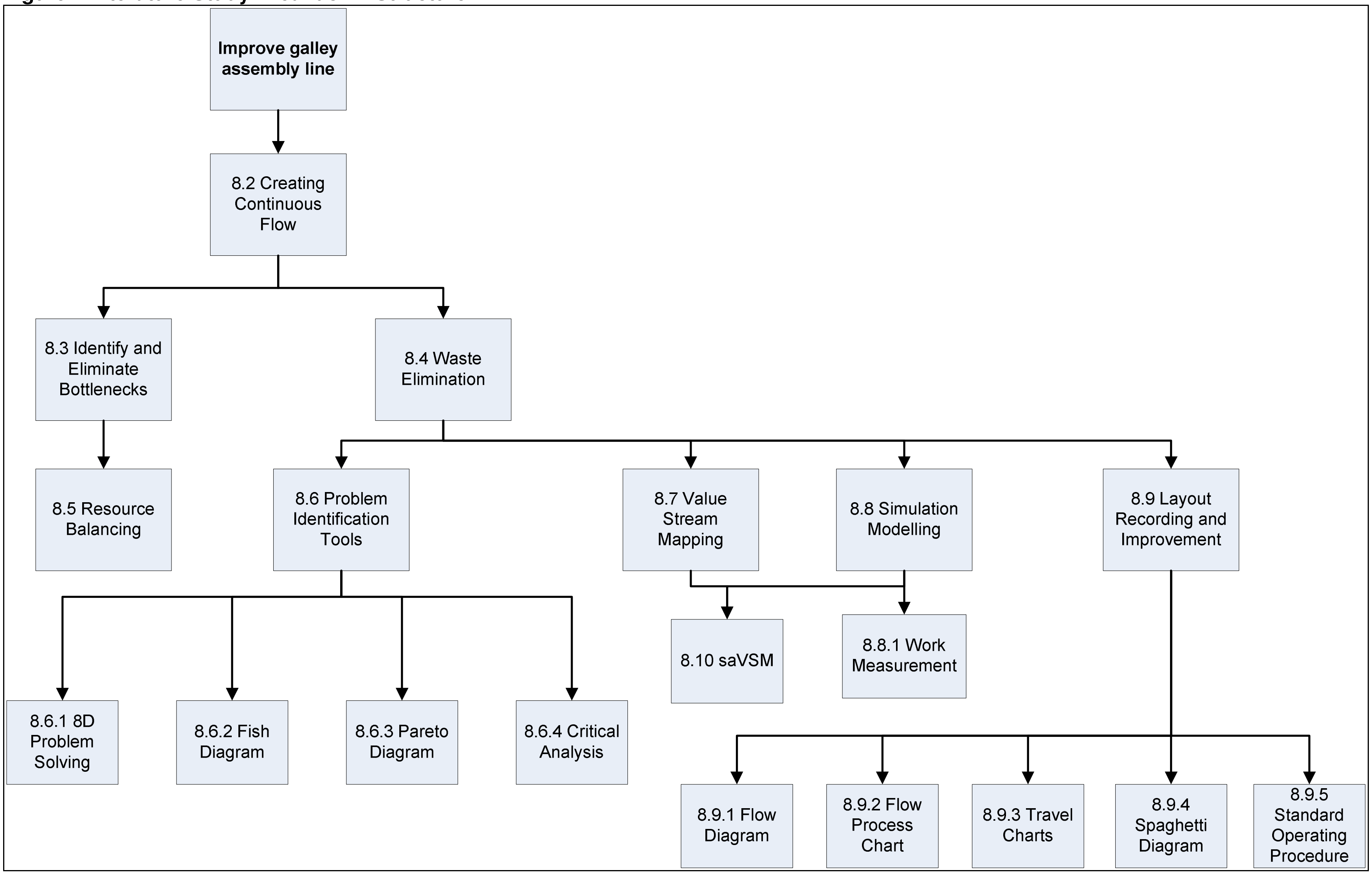
- Land
- Materials
- Plant, machines and tools
- The services of men

or, as in generally the case, a combination of all four. The International Labour Office (1979) also states that the factors tending to reduce productivity are:

- Work content added due to the product
- Work content added due to the process or method
- Ineffective time due to the management
- Ineffective time within the control of the worker

If all the factors that reduce productivity can be eliminated, the minimum time for the production of a given output and hence the maximum productivity is achieved. With the above factors, problem statement and deliverables in mind, some appropriate methods, tools and techniques will be investigated to find a solution to the problem the production line is facing at present. A breakdown structure has been compiled to show the breakdown of the different methods, tools and techniques and their relationship to one another. The breakdown structure appears as Figure 4 and each item is addressed below.

Figure 4 Literature Study Breakdown Structure



8.2 Creating continuous flow

Continuous flow is the flow of products at a steady, consistent velocity through the assembly line. The goal of continuous flow is to increase the velocity of production and to make the production cycle more predictable. According to Hirano (1990) the eight basic steps to implement continuous flow in a manufacturing environment are:

- Perform work statement analysis
- Locate equipment in the proper sequence
- Design the cell with minimum distance and compact equipment
- Strive to produce and move one piece at a time
- Separate people from machines
- Develop multi-skilled employees
- Produce at the rate of customer consumption
- Balance operations in the cell

Creating continuous flow in a production line is a time consuming task. A thorough process analysis must be done to determine where valuable time is wasted. There are a few ways of creating continuous flow in a production line. These methods are divided into two main groups: Identify and eliminate bottlenecks and waste elimination. Once all the bottlenecks, which limit the amount of throughput, are managed and all the unnecessary time consuming wastes are eliminated or reduced to a minimum, drastic improvements will be seen.

8.3 Identify and Eliminate Bottlenecks

Chase et al (2004) defines a bottleneck as any resource whose capacity is less than the demand placed upon it. These bottlenecks become the pacemakers in the manufacturing system. By eliminating or reducing the bottleneck time, the whole system will be improved. As the process is being improved, it may seem that the known bottleneck has moved to another position in the manufacturing line. This is because in every production line there will always be a process that restricts the flow rate. Therefore it is important to manage the bottlenecks in terms of the demand.

8.4 Waste Elimination

Waste elimination is one of the most effective ways to increase the profitability of any business. Processes either add value or waste to the production of a good or service. According to Hines and Rich (1997) the seven wastes were originally developed by Toyota's Chief Engineer Taiichi Ohno as the core of the Toyota Production System, also known as Lean Manufacturing. Waste is present in every manufacturing environment. Production flow rate can only be improved when these wastes are identified and reduced. There are in most cases seven wastes that occur in daily production in manufacturing companies. These seven wastes are:

- Overproduction: Producing more than the customer has ordered
- Bad Quality: Making parts that cannot be sold or have to be reworked
- Over Processing: Doing more work to a part than required
- Transport: Moving or handling parts unnecessarily
- Waiting: Delay caused by waiting for parts etc
- Operator motion: Extra walking, looking for things, bending, stretching and turning
- Stock: Too much raw material, too many unfinished parts, too much finished stock

8.5 Resource Balancing

The amount of work at a bottleneck can be reduced by either adding extra resources to reduce the amount of work or by improving the current method. This may imply the employment of extra workers or purchase of extra machines to increase throughput and release the pressure on the assembly line. A careful analysis must be done on each resource at each process in the production line to determine their capacity and if extra resources are required.

Niebel et al (2003) states that the rate of production is dependent on the slowest operator in the assembly line. The slowest operation can be determined by the following formula:

$$Slowest\ Operation = \frac{Standard\ minutes\ per\ part}{Number\ of\ resources}$$

Once the slowest operation has been calculated it can be used to determine where more resources should be added to increase the flow rate of products through the production line.

8.6 Problem Identification Tools

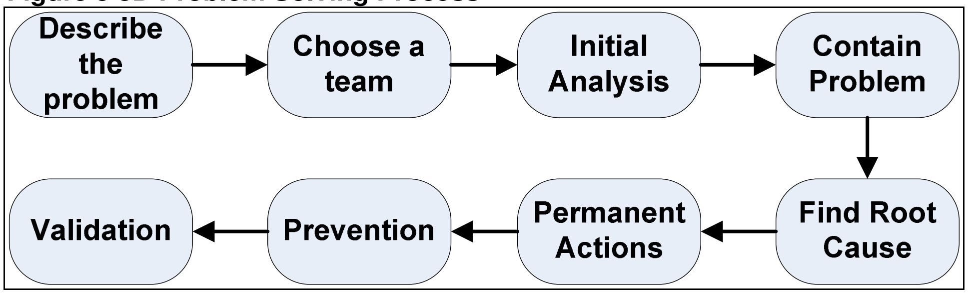
Niebel et al (2003) states that whether designing a new work centre or improving an existing operation, the most crucial step is the identification of the problem in a clear and logical form. A variety of problem solving tools is available, and each tool has specific applications. According to Chung (2004) fish diagrams and Pareto charts are two tools available for problem identification and were originally developed for the manufacturing environment.

8.6.1 Eight Disciplines Problem Solving technique

The Eight Disciplines Problem Solving technique is a method used to approach and to resolve problems. According to Wikipedia it is used to identify, correct and eliminate problems. The methodology is useful in product and process improvement. It establishes a standard practice, with an emphasis on facts. It focuses on the origin of the problem by determining the root cause. The technique was developed by the Ford Motor Company and today officially titled "Global 8D"(G8D) which is the current global standard for Ford and many other companies in the automotive supply chain. Recently, the eight disciplines technique process has been employed extensively outside the auto industry. As part of Lean initiatives, it is used within Food Manufacturing, High Tech and Health Care industries.

Eight Disciplines technique is a problem solving technique that provides you with a structured approach and prevents you from taking short cuts to solving the problem. It also assists you where the root cause/s is unclear and gives you a guide to successful improvement implementation. The technique consists out of the following steps:

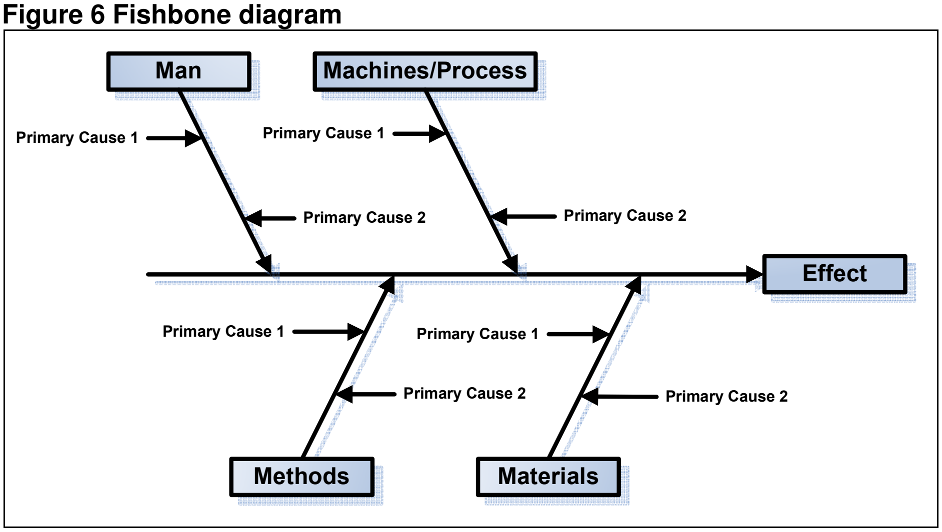
Figure 5 8D Problem Solving Process



8.6.2 Fish diagram

According to Niebel and Freivalds (2003) fish diagrams, also known as cause-and-effect diagrams, were developed by Ishikawa in the early 1950s while working on a quality control project. The purpose of this chart is to identify the contributing factors (causes) to an occurrence of a typical undesired event or problem (effect). The fishbone diagram looks similar to the bones of a fish. The head of the fish is labelled with the problem or effect. In a manufacturing environment the major bones are for man, machine, material and methods. After the fishbone diagram is completed, only the most important sources or causes of the problem can be focused on.

Figure 6 Fishbone diagram



8.6.3 Pareto Chart

Pareto charts help to break down a problem into the relative contributions of its components. They are based on the common empirical finding that a large percentage of problems are due to a small percentage of causes, better known as the 80-20 rule. This rule states that 80% of the problem is caused by 20% of the factors. This allows the analyst to concentrate the greatest effort on the few items that produce most of the problems.

8.6.4 Critical Analysis Technique (5W1H)

According to Sugiyama (1989) the critical analysis technique is an important tool that develops the complete facts of a situation and then examines the reasons for them. It is useful in any situation that needs to be understood more concretely. Using the critical analysis framework abstract arguments are effectively turned into concrete debates. Table 1 is a critical analysis template that will aid in problem identification. Certain questions will be completed by the analyst regarding an operation or current method. It is also required from the analyst to consequently identify and evaluate alternatives.

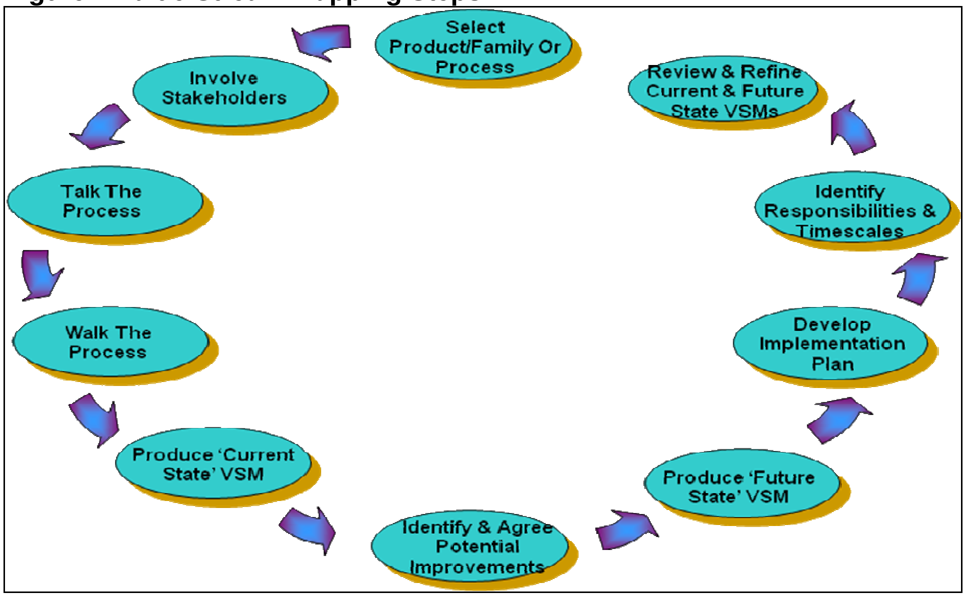
Table 1 Critical Analysis Technique

CRITICAL ANALYSIS TECHNIQUE			
PRESENT METHOD		ALTERNATIVES	SELECTED ALTERNATIVE
Purpose – What is achieved?	Is it necessary? [yes/no] If yes - why?	What else could be done?	What?
Means - How is it done?	Why that way?	How else could it be done?	How?
Place – Where is it done?	Why there?	Where else could it be done?	Where?
Sequence – When is it done?	Why then?	When else could it be done?	When?
Person – Who does it?	Why that person?	Who else could do it?	Who?

8.7 Value Stream Mapping (VSM)

Value Stream Mapping serves as a starting point to help recognize waste and identify its causes. It is a method that consists of visually mapping a product's production path, including materials and information flow, from dock-to-stock. Rother and Shook (1999) states that value stream mapping facilitates the process of lean implementation by helping to identify the value-added steps in a value stream, and eliminating the non-value added steps (waste). Steps for constructing a Value Stream Mapping diagram are:

Figure 7 Value Stream Mapping Steps



To construct a value stream map, there are special symbols that need to be used to create universal understanding of the process. (Please refer to Appendix C for the symbol definition) In order to draw the value stream map of the future state, the takt time must be known. The takt time helps to set the pace for production and is calculated from the customer demand rate. The takt time indicates at what rate the customer is buying one unit and must also be the target rate for producing products to create continuous flow. According to Rother and Shook (1999) the takt time formula is:

$$Takt\ Time = \frac{Your\ available\ work\ time\ per\ shift}{Customer\ demand\ rate\ per\ shift}$$

It is an essential tool because:

- It helps with the visualization of more than just the single process level in production, and also makes flow visible
- Helps to see more than just the waste by making the sources of the waste also visible

- By helping to design the whole door-to door flow operation, it forms the basis of an implementation plan

- Makes the linkage between information flow and material flow visible, which no other tool does

- Much more useful than quantitative tools and layout diagrams that produce a tally of non-value-added steps, lead time, distance travelled, the amount of inventory, and so on. It is a qualitative tool by which the detail of the facility operation is described in order to create flow. A sense of urgency is created by numbers, but value stream mapping is good for describing the actions to be performed to affect those numbers

According to Rother and Shook (1999) despite value stream mapping's success, it has some drawbacks:

- It is a paper and pencil based technique used primarily to document value stream. It is composed by physically "walking" along the flow and recording what happens on the floor. This will limit both the level of detail and the number of different versions that can be handled.

- Not a high level of complication can be addressed by value stream mapping

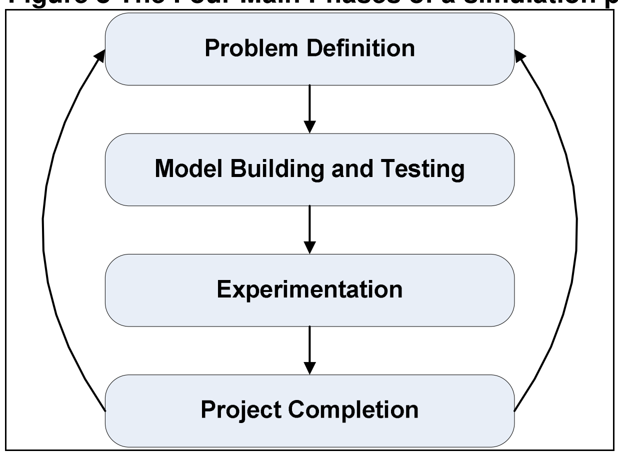
- Revealing as a value stream map can be, many people fail to see how it translates into reality. So, the value stream risks ending up as a nice poster, without much further use.

8.8 Simulation Modelling

Kellner et al (1998) defines a simulation model as a computerized model which represents some dynamic system or phenomenon. One of the main motivations for developing a simulation model or using any other modeling method is that it is an inexpensive way to gain important insights when the costs, risks or logistics of manipulating the real system of interest are prohibitive. Simulations are generally employed when the complexity of the system being modeled is beyond what static models or other techniques can usefully represent. Tompkins et al (2003) states that simulation does not provide an optimum solution, but by asking enough "what-if" questions the configuration of the system that best satisfies the criteria can be chosen. If the production line is simulated, visibility is created and the problem can immediately be identified.

Bhatia and Robinson (1995) suggest the following four main phases in a simulation project:

Figure 8 The Four Main Phases of a simulation project



To support the above mentioned statements Tompkins et al (2003) lists reasons for using simulation models:

- When a mathematical solution cannot be obtained easily or at all
- Selling the facilities plan to management
- Explaining to operating personnel how a proposed system will function
- Testing the feasibility of a proposed system
- Developing throughput and storage requirements
- Predicting the impact of a change in the physical system, the environment, or operating procedures

Tompkins et al (2003) also states that simulation can result in improved understanding of the facilities plan in the following ways:

- The process of creating a simulation model requires a detailed understanding and documentation of the activity being simulated, which will lead to the discovery of new information.
- The teaching of some concepts is quite difficult because of the complex interrelationship among variables. Simulation can be used in a "gaming" sense to relate these complex interrelationships.
- The orientation of employees on a system can often create significant problems. Simulation can be used to orientate existing employees to new systems or new employees to existing systems. Employees may be trained on a simulator to get a greater understanding of the system.

Simulation can be a very valuable tool for exploring current operations in the manufacturing sector, evaluating alternative policies and assisting decision makers in initiating and implementing change. Simulation aids in balancing resources, managing bottlenecks and eliminates the risk of failure of a new method that will be implemented on the shop floor. There are various software packages available that are well- suited for the simulation of material handling/ manufacturing systems. One of the disadvantages of using simulation modelling is that special training is required before a person can accurately and correctly develop a computer simulation model. Another disadvantage is that a simulation model is still only a model of the process and does not depict reality. It only depicts an approximation of reality. The software packages are Arena, AutoMod, eM-Plant, Factory Explorer, GPSS/H (and SLX), GPSS World for Windows, MAST Simulation Environment, ProModel 2001, Quest, Simscript II.5, Simul8, Taylor ED, and Witness.

8.8.1 Work measurement

The fundamental purpose of work measurement is to set time standards for a job. When performing a work measurement study a trained person uses a stopwatch or video camera and a work measurement form to record the time taken by an operator or machine to perform a certain task. Multiple observations of each task are necessary to establish accurate time standards in a manufacturing or assembly process. According to Chase et al (2004) the reasons for such time standards are:

- To schedule work and allocate capacity
- To provide an objective basis for motivating the workforce and measuring workers' performance
- To bid for new contracts and to evaluate on existing ones
- To provide benchmarks for improvement

Work measurement consist of two direct observational methods, namely time study and work sampling. Time study is where a stopwatch is used to time the work while work sampling entails recording random observations of a person or team at work. One drawback of work sampling is that it does not provide as complete a breakdown of elements as time study. Another difficulty with work sampling is that observers, rather than following a random sequence of observations, tend to develop a repetitive route of travel.

8.9 Layout recording and improvement

Niebel et al (2003) states that transport are one of the most obvious wastes that occur in daily production, transporting products from one workstation, or machine, to the next. The Material Handling Institute conducted a study which revealed that between 30 and 85 percent of the cost of bringing a product to the market is associated with material handling. Material handling does not only waste time, but damages the products and may lead to rework or scrap. The layout of the facility plays an important role in reducing transport waste and it should be determined where the operation should be in order to yield least amount of material handling.

According to Meyers (1993) if the flow of material is improved, it will automatically reduce production costs. The shorter the flow through the assembly line, the better. In order to enhance flow in the plant layout and material handling, the following cost reduction formula can be helpful:

- Eliminate steps in the process
- Combine steps in the process
- Change the sequence of the process to reduce distances and time
- Simplify the operation by moving steps closer together and/or automate the movements between steps

Any plant layout must be designed with a goal in mind. Meyers (1993) states the goals of plant layout and material handling must:

- Minimize unit cost
- Optimize quality
- Promote the effective use of people, equipment, space and energy
- Provide for employee convenience, employee safety and employee comfort
- Control project cost
- Achieve the production start date
- Achieve miscellaneous goals

8.9.1 Flow Diagram

According to Freivalds and Niebel (2003) the flow diagram is a pictorial representation of the layout of floors and buildings, showing the locations of all activities on the flow process chart. The direction of flow is indicated by placing small arrows periodically along the flow lines. The flow diagram is a helpful supplement to the flow process chart because it indicates backtracking and possible traffic congestion areas, and it facilitates developing an ideal plant layout.

8.9.2 Flow Process Chart

Flow Process chart is a process chart setting out the sequence of the flow of a product or a procedure. The process flow chart is especially valuable in recording nonproduction hidden costs, such as distances traveled, delays, and temporary storages. Once the nonproduction periods are highlighted, analysts can take steps to minimize them and reduce their costs. A set of standard process chart symbols (ASME, 1974) must be used to construct the process flow chart.

This tool facilitates the elimination or reduction of the hidden costs of a component. Since the flow process chart clearly shows all transportations, delays, and storages, the information it provides can lead to a reduction of both the quantity and duration of these elements. Also, since distances are recorded on the flow process chart, the chart is exceptionally valuable in showing how the layout of a plant can be improved.

8.9.3 Travel Charts

Freivalds and Niebel (2003) suggest that before designing a new layout or correcting an old one, analysts must accumulate the facts that may influence the layout. Travel or from-to charts can be helpful in diagnosing problems related to the arrangement of departments and service areas, as well as the location of equipment within a given sector of the plant. The travel chart is a matrix that presents the magnitude of material handling that takes place between two facilities per time period. The unit identifying the amount of handling may be whatever seems most appropriate to the analyst.

Figure 9 Travel Chart

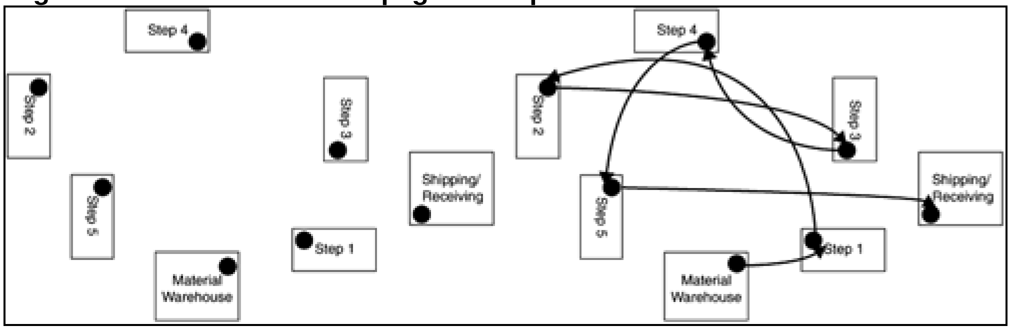
From Departments \ To Departments	A	B	C	D	E	F	G
A		23	12	35	65	16	95
B			37	45	80	40	80
C				18	50	12	67
D					119	63	60
E						49	30
F							79
G							

8.9.4 Spaghetti Diagram

According to Wikipedia a Spaghetti Diagram or Physical Process Map is the simplest Lean Sigma tool. It demonstrates the physical flow of an entity or multiple entity types and the associated travel distance for a single cycle of a process. It is a graphical representation of travel distance and travel patterns.

Wikipedia also states that a spaghetti map is a particularly useful tool when there is excessive movement of an entity or entities through a process. It is a highly simple, visual tool; it can help streamline a process and is part of the standard toolkit used when running a kaizen event. The map shows existing problems in a process and also communicates the potential benefit of change to a new layout or flow.

Figure 10 Construction of a Spaghetti Map



8.9.5 Standard Operating Procedure (SOP)

A Standard Operating Procedure (SOP) describes the appropriate sequences and objectives for each activity. According to Nakagawa (2004) the target duration for repetitive activities in a project can be achieved by preparing a Standard Operating Procedure and familiarising the workers in advance with the procedures in the documents. The Standard Operating Procedure must satisfy the following requirements:

- Provides the steps and details necessary to manufacture the part with minimum waste including sequence and duration of each activity
- Uses worker-friendly, easy-to-understand language with simple statements and terms
- Content must be easily revised

Creating a Standard Operating Procedure has the following benefits:

- Building understanding of resource requirements and utilization
- Improves ability to prioritize and measure process improvements
- Differentiates normal and abnormal events
- Exposes wastes hidden without standard operations

8.10 Simulation Aided Value Stream Mapping (saVSM)

Value Stream Mapping (VSM) is a concrete mechanism that empowers companies to go beyond Lean thinking and actually become Lean organizations. Value Stream Mapping is the most important step in implementing Lean processes and starts with identification of the value stream for each product line.

According to Narasimhan (2007) one limitation of value stream mapping is that, it is quite static in nature, being a paper and pencil approach. By using modelling and simulation tools, in conjunction with value stream mapping, the authors have countered this limitation by providing a dynamic framework and toolkit, where current states can be simulated to identify the dynamic bottlenecks. Additionally the future state can be evolved based on practical simulations with improved processes and performance measures. This approach is called simulation aided value stream mapping (saVSM).

Narasimhan (2007) also states that this saVSM approach involves effort in modelling along with Value Stream Mapping, thereby ensuring excellent visualization of the processes, and quicker analysis of process improvements. A future state map can be finalized quicker with concrete quantified benefit estimates. The ability to not only plan deployment of a Lean process, but also validate and test it using simulation tools is the key differentiator of simulation aided value stream mapping which ensures quick, low cost and sustainable deployment.

Lian and Van Landeghem (2002) propose the following method for Simulation Aided Value Stream Mapping:

- Phase one: Current and future state Value Stream Map of one product according to the classical method
- Phase two: Built a simulation model based on the current and future state maps of phase one
- Phase three: Investigate different conditions and parameters with the usage of simulation models

The output of a simulation model is very important and will be used to judge any changes that are made to the simulation model. There are a few key measurements for a simulation model namely:

Table 2 Key Measurements

Key Measurement	Definition of measurement
Throughput (TH)	The average output of a production process per unit time
Work in Process (WIP)	The inventory between start and end points of a product routing
Lead Time (LT)	The total time a customer must wait to receive a product after placing an order
Utilization	Fraction of time a workstation is not idle for the lack of parts

Francis and Taylor (2002) completed a case study at a high-performance motion control products manufacturing plant in Southeast America, which focussed on an approach to complement value stream mapping with simulation modelling. They concluded that simulation aided value stream mapping must be applied to a process where there is product complexity, parallel processing steps and different number of shifts used across a production line. Similarly, Lian and Van Landeghem (2007) concludes that by this approach current and future state value stream maps are transformed automatically into dynamic simulation models. The enhanced information, obtained from the simulation results, can provide feedback to guide continuous improvement and hopefully will lead more enterprises to a lean status.

There are various software options available to combine value stream mapping and simulation. The first option is Process Simulator 2007 Lite that will enable the user to simulate Microsoft Visio flowcharts, value stream maps and workflow diagrams. Secondly Gahagan (2005) developed a VSM Modules in Arena. Arena's Professional Edition provides the tools to create a custom template of data objects with both graphic and data properties. The template contains three objects: process, delivery, and shipment.

9. Selection of Appropriate Methods, Tools and Techniques

A manufacturing environment cannot be improved over night; therefore one step should be taken at a time. Many different methods, tools and techniques have been discussed but due to the nature of the project, combinations of industrial engineering methods, tools and techniques will be used to improve the production flow rate at Aerosud. Approaches used by Lian and Van Landeghem (2002) in their case study will be used as guidelines in order to investigate the use of Simulation Aided Value Stream Mapping (saVSM) in a slow moving manufacturing environment.

9.1 Simulation Aided Value Stream Mapping (saVSM)

Simulation Aided Value Stream Mapping is a method which combine value stream mapping with simulation modeling to achieve quicker analysis of process improvement as well as ensuring excellent visualization of the processes. Therefore the most appropriate method to create continuous flow in the assembly line at Aerosud will be to apply Simulation Aided Value Stream Mapping in conjunction with some other industrial engineering methods, tools and techniques. In doing so, bottlenecks can be identified and managed and the effect of the current and proposed layout can be determined. The following method for Simulation Aided Value Stream Mapping will be applied to the assembly line:

- Phase one: Current and future state Value Stream Map of one product according to the classical method
- Phase two: Built a simulation model based on the current and future state maps of phase one
- Phase three: Investigate different conditions, parameters and layouts with the usage of simulation models

9.2 Problem Identification

The following methods will be used to define and understand the different problems:

- Fishbone Diagram
- Pareto Chart
- Critical Analysis Technique

Because the Fishbone Diagram shows hypothesized relationships between potential causes and the problem under study, it will be used as a problem identification tool. Once the fishbone diagram is constructed, the analyst would proceed to find out which of the potential causes were in fact contributing to the problem. The Pareto chart help to break down a problem into the relative contributions of its components and will be used to help show out the biggest contributors to the problems the assembly line is facing at present. The Critical Analysis Technique is an important tool that develops the complete facts of a situation and then examines the reasons for them. It is useful in any situation that needs to be understood more concretely. This will be a helpful tool to identify the current problems of the assembly line.

The above mentioned problem identification tools will be used on the first phase of the simulation aided value stream mapping method. Although the eight disciplines problem solving technique is a very successful method, it will not be used in the project because of the fact that it is a team effort end not a technique an individual can apply alone. Because the eight disciplines problem solving technique also contains the fishbone diagram and critical analysis, there is no need to use the method; it will only result in double work.

9.3 Work Measurement

Time studies will be used to establish the complete breakdown of the elements that are measured. Also time studies will be used to establish accurate time standards for the assembly line. Time studies will be used in the first phase of the simulation aided value stream mapping method.

9.4 Value Stream Mapping

Value Stream Mapping serves as a starting point to help recognize waste and identify its causes. It is a method that consists of visually mapping a product's production path, including materials and information flow, from dock-to-stock. It is an essential tool because it helps with the visualization of the process and much more useful than quantitative tools and layout diagrams. It is a qualitative tool by which the detail of the facility operation is described in order to create flow. Value stream mapping is only a paper and pencil based technique and is limited by the number of different versions that can be handled. Also not a high level of complication can be addressed by value stream mapping.

9.5 Simulation Modelling

Simulation modelling is an inexpensive way to gain important insights when the costs, risks or logistics of manipulating the real system of interest are prohibitive. Simulation does not provide an optimum solution, but by asking enough "what –if" questions the configuration of the system that best satisfies the criteria can be chosen. If the production line is simulated, visibility is created and the problem can immediately be identified. Simulation will be used in this project to achieve the following objectives:

- To provide statistical data and output
- To effectively represent a given facility layout (scenario)
- To determine which alternative is the most economically viable option
- To dynamically represent the Value Stream Map of the current and future state

9.6 Layout recording and improvement

Layout recording and improvement will be established by using Spaghetti diagrams and Flow diagrams. Spaghetti map will be used because it is a particularly useful tool when there is excessive movement of an entity or entities through a process. The map shows existing problems in a process and also communicates the potential benefit of change to a new layout or flow. The flow process chart clearly shows all transportations, delays, and storages, the information it provides can lead to a reduction of both the quantity and duration of these elements. The flow diagram will be used because it is a helpful for indicating backtracking and possible traffic congestion areas, and it facilitates developing an ideal plant layout. The use of travel charts is not necessary because the information it provides will be supplied by the other techniques mentioned above. Standard Operating Procedures (SOP) will be used because it provides the steps and details necessary to manufacture the galley with minimum waste including sequence and duration of each activity. The Standard Operating Procedures also improves the ability to prioritise and measure process improvements.

10. Hypothesis

One of the reasons for the above mentioned research in Section 8 is to test the following hypothesis:

Aerosud can be more effective if they combine simulation modelling with their current Value Stream Mapping (VSM) approach.

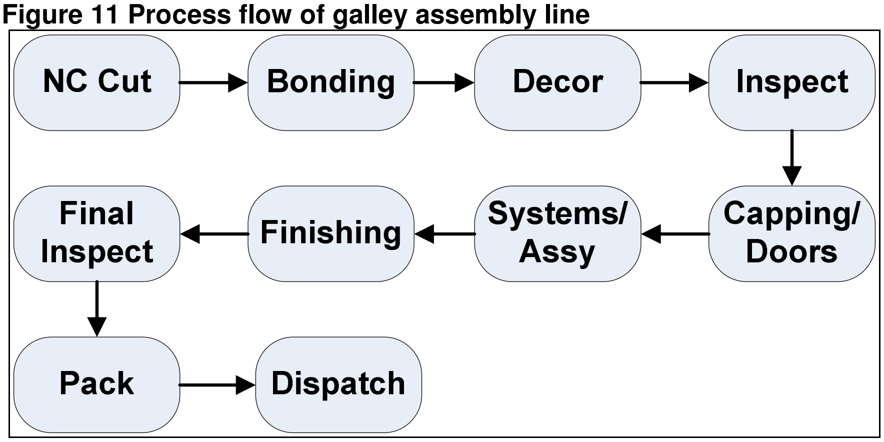
11. Data and Information Gathering (DO)

As mentioned in the above sections, Aerosud is experiencing trouble with the productivity of the galley line, which results in inconsistent lead times and increased costs. The assembly line is also struggling to keep up with the current demand. One of the first steps in information and data gathering is to understand the requirements. The understanding of operations, keeping the problem statement in mind, will aid in the identification of areas that can be focused on. This is also the first specific objective stated in the project aim. The rest of the objectives can be completed once the data requirements have been identified and the process defined.

11.1 Process and events

Raw material is received from overseas suppliers and stored in the stores. The planning department correlates with the stores on a daily basis to check the level of inventory. The NC Cutting cell receives panels weekly from the stores that need to be cut to specification. From there the panels are moved to the bonding and décor sections where a variety of processes take place. The first inspection takes place after the décor cell. In the systems cell the water system, drain system and a variety of other systems are fit into the galley. In the finishing cell an identification number is attached to the galley and the galley is cleaned and prepared for final inspection. The cleaning and sealing of cappings and corners with silicon also takes place in the finishing cell. Thereafter final inspection of the galley takes place, followed by packing and dispatch of the galley. Please refer to Appendix C for the galley assembly line layout. The overview of the process can be seen in the following figure:

Figure 11 Process flow of galley assembly line



11.2 Current State Analysis and Value Stream Map

After thorough analysis of the assembly line and discussion with the workers, the current state value stream map has been drawn up. Please refer to Appendix C for an explanation of the value stream mapping icons. The map will serve as a starting point for further study of the assembly line. The current state drawing is used to understand how the area currently operates. The current state map can be viewed in Figure 12. According to Rother and Shook (1999) the definitions of the value stream map components are as follows:

- *Cycle time(C/T):* How often a part or product actually is completed by a process, as timed by observation. Also, the time it takes an operator to go through all of their work elements before repeating them

- *Value Added Time (VA):* Time of these work elements that actually transform the product in a way that the customer is willing to pay for

- *Lead Time (L/T):* The total time from customer order to delivery of the desired product

- *Not Right First Time (NRFT):* Percentage of product that needs to be reworked because it doesn't conform to customer specification

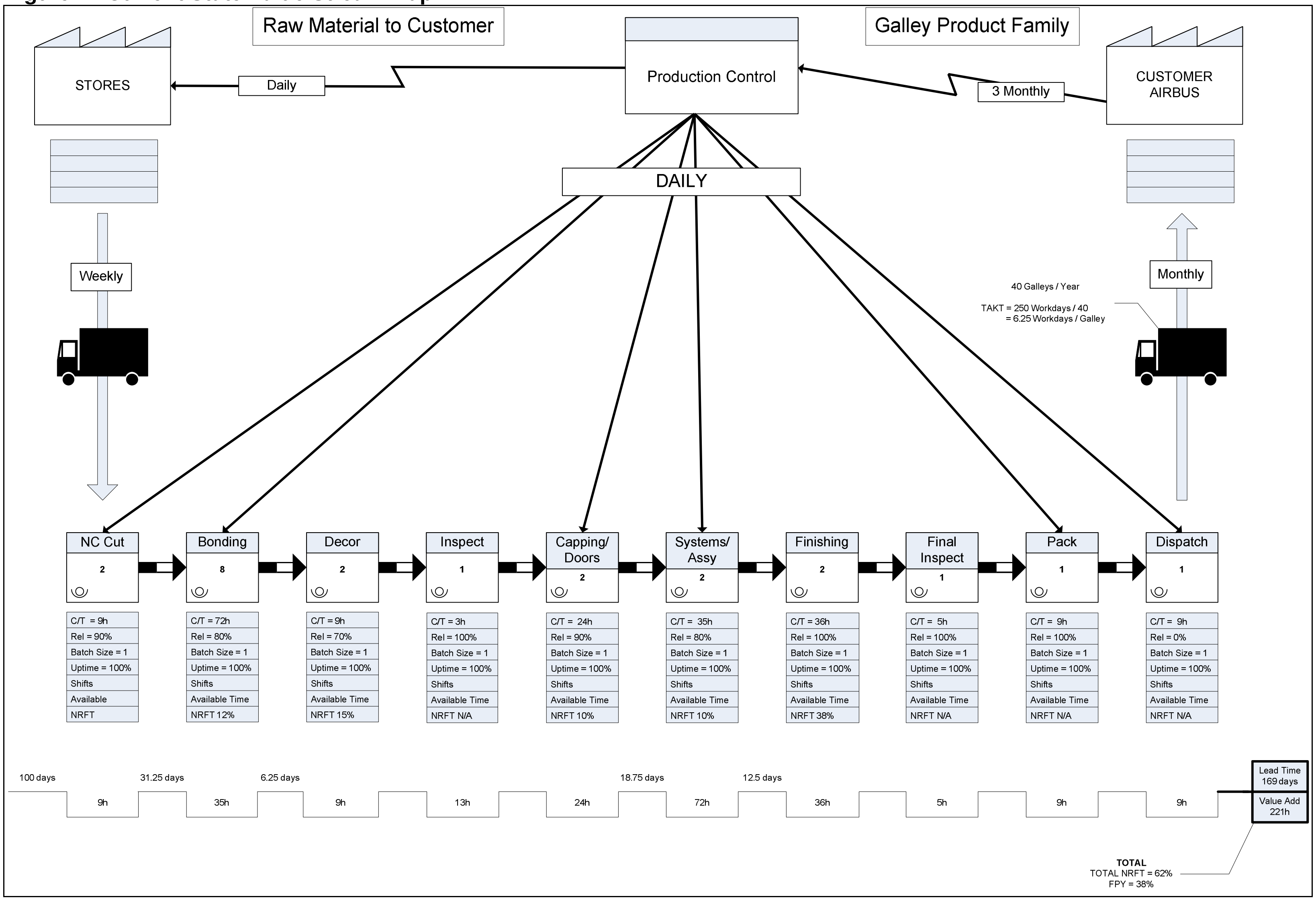
- *Reliability:* This measure shows the reliability of the output of the cell

There is a wide variety of information that is displayed on a value stream map. Table 3 summarises the data of the current state of the galley assembly line.

Table 3 Current State information

Cell	Cycle Time	No. of workers	Reliability	Not Right First Time (NRFT)	Value Added Time	Lead Time
NC Cut	9h	2	90%	-	9h	100days
Bonding	72h	8	80%	12%	35h	45days
Décor	9h	2	70%	15%	9h	9days
Inspect	3h	1	100%	N/A	13h	-
Capping	24h	2	90%	10%	24h	-
Systems/Assy	35h	2	80%	10%	72h	27days
Finishing	36h	2	100%	38%	36h	18days
Final Inspect	5h	1	100%	N/A	5h	10days
Pack	9h	1	100%	N/A	9h	10days
Dispatch	9h	1	0%	N/A	9h	10Days

Figure 12 Current State Value Stream Map



A wide variety of processes are performed in each cell of the assembly line. In order to better understand the processes involved in the assembly line, the main processes have been summarised in Table 4.

Table 4 Summary of operations in the different cells

Nr	Cell name	Processes in cell
1	NC Cutting	Cutting of panels to specification
2	Bonding	➢ Inspection ➢ Putting inserts in ➢ Dry fitting of plates ➢ Potting sides of plates ➢ Bonding plates ➢ Cleaning and sealing of sides ➢ Bonding subassemblies ➢ Final finishing to galley
3	Décor	➢ Attachments to galley
4	Inspection	➢ Inspection of galley
5	Capping/Doors	➢ Measure capping ➢ Dry fit capping on doors and panels ➢ Bond Capping
6	Systems/Assy	➢ Doors are aligned and assembled ➢ Upper attachments and brackets fastened ➢ Bonding of divider, bump strips and ventilation system ➢ Basin and counter put in place ➢ Assemble and connect water, drain, chiller, ventilation, electrical and final finishing systems ➢ Test all systems
7	Finishing	➢ Information are attached to the galley ➢ Capping and corners are sealed and cleaned with silicon ➢ Galley cleaned and prepared for inspection
8	Final Inspect	➢ Inspection of galley
9	Pack	➢ Wrapping and packing of galley
10	Dispatch	➢ Deliver to customer

11.3 Profit Calculation

Some of the financial information are regarded as confidential information and can't be made public in the project. The information will be used in the calculations but the exact amounts will not be mentioned. A recovery rate per hour of R240 per labourer will be used as the labour cost. The recovery rate is the total amount that a labourer will cost Aerosud per hour. The labour cost is also influenced by the number of workers in the galley assembly line. Vartan cost is similar to the cost of reworking. The galley is inspected in Hamburg and if the galley don't satisfy the given quality specifications, it must be reworked at a cost to the company. The following costs will also be included:

Table 5 Cost Identification

Cost	Description
Indirect cost	Is a cost that cannot be easily and conveniently traced to a specified cost object
Variable cost	Cost that varies, in total, in direct proportion to changes in the level of activity
Fixed cost	Cost that remains constant, in total, regardless of changes in the level of activity
Non Stock cost	Includes shipping cost and any other cost that needs to be included

The selling price are calculated in dollars and converted to rand by the rand dollar exchange rate at the given time. The selling price is treated as confidential information. The galley ship sets per month is the amount of galleys that will be delivered to the customer. The amount that will be delivered to the customer will greatly influence the profitability of the galley assembly line. A profit calculation spreadsheet was developed in Excel. The spreadsheet calculates the profit per year, profit per month and even the profit per ship set. All the above mentioned costs have been included in the spreadsheet. The calculation assumptions are illustrated in Figure 13. Figure 14 illustrates the spreadsheet interface. For a complete view of the model and the calculations please refer to the cd, included in the back of this book. The data discussed in this section will be used at a later stage.

Figure 13 Calculation Assumptions

Calculation Assumptions:	Base Value	Dollars
SELLING PRICE / SHIPSET (Dollars)	[redacted]	[redacted]
MATERIAL COST / SHIPSET	[redacted]	[redacted]
NO. OF PEOPLE	25	25
RATE PER HOUR	R 240	$30
LABOUR COST PER PERSON @ R240	R 43,499	$5,437
LABOUR COST FOR GALLEY LINE / MONTH	1,087,463	$135,933
VARTAN COST / SHIPSET (E)	€ 4,500	$6,750
INDIRECTS / MONTH	R385,000	$48,125
NON STOCK - SHIPPING, S&T AND OTHER / MONTH	R400,000	$50,000
EXCHANGE RATE : US Dollar ($) - Rand (R)	8	8
EXCHANGE RATE : Euro - Rand (R)	12	12

Figure 14 Cost Calculation Interface

GALLEY DATA	
GALLEY SHIPSETS / MONTH	2.2

26.40 shipsets / year

PROFIT			
REVENUE	MONTHLY INCOME	Income from 2.2 Galley Shipsets	[redacted]
COST	FIXED	Shopfloor Labour / Month	R 1,087,463
		Vartan / Month	R 54,000
		Indirect Labour / Month	R 385,000
	VARIABLE	Material Cost / Month	R 924,000
		Non Stock Cost / Month	R 400,000

TOTAL PROFIT PER MONTH	**-R 562,463**
TOTAL PROFIT PER SHIPSET	**-R 255,665**
TOTAL PROFIT PER YEAR	**-R 6,749,556.00**

11.4 Current State Simulation Model

A simulation model was built using Rockwell's Arena 7.01 and was created to resemble the operations involved in the galley assembly line. The primary objective of the simulation models were to provide an interactive dynamic value stream map where to verify outcomes to different changes to the assembly line and be able to visually see the effect of the change on the assembly line. A few assumptions were made in order to compensate for uncertainties that had not been built into the model. The assumptions are as follows:

No absenteeism

No absenteeism of employees working on the galley assembly line is taken into consideration in the model. The reason therefore is that everyone should be skilled in all areas and be able to take over if a critical process cannot be performed due to absenteeism.

No Overtime

No overtime is built into the model. There are only five working days a week and 7 productive hours a day. The actual working hours are 9 hours per day; however one hour is allocated to lunch and tea breaks. Furthermore, an extra hour is taken into account for human fatigue and bathroom breaks. All the orders must be met during these working hours.

Raw material is always available in full

The raw material in the model represents the panels that are delivered from the stores to the NC cutter. Raw material is delivered on a weekly schedule to the cell. Raw material is always available.

Rejection and reworking of parts

The rejection and rework delay will be assumed to take an average of 5 minutes. The reworking procedures entitles that the part is sent back to the previous cell where it will be reworked and then be inspected again.

11.4.1 Pieces of the simulation model

The simulation model for the current state value stream map was built using the basic building blocks in Arena. The main objective was to resemble the value stream map in a dynamic form. The various parts that the simulation model will consist of:

- *Entities*

  Entities are the dynamic objects in the simulation. They usually are created, move around for a while, and then are disposed as they leave. The entities are represented by raw material that moves along in the assembly line and are transformed into the final product.

- *Resources*

  Resources represent all the different people working in the assembly. Specific names and processing values are assigned to each resource.

- *Processes*

  Processes require resources to be able to function. Raw material is transformed to the final product by the different processes.

- *Queues*

  The purpose of a queue is to supply a waiting place for the entity when the resource that it needs to seize is tied up by another entity.

- *Attributes*

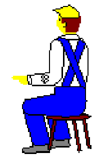
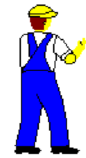
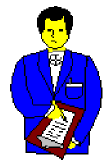
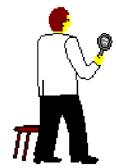
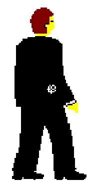
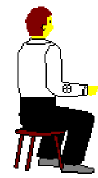
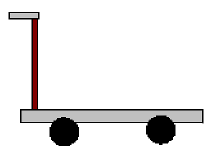
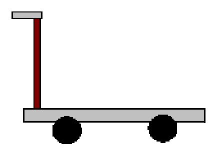
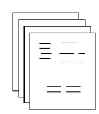
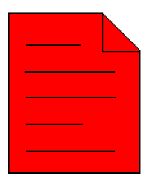
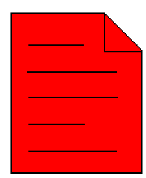
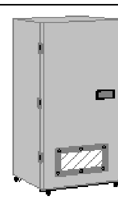
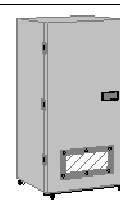
  An attribute is a common characteristic of all entities, but with a specific value that can differ from one entity to another. These attributes that are assigned to each entity set a certain path so that the products can be processed.

Table 6 summarizes the building blocks that were used to simulate the above mentioned pieces of the model. Furthermore, the animation used in the model can be viewed in table 7.

Table 6 Building blocks of the simulation model

Building Block	Description
Create	➢ Raw material arriving according to a schedule ➢ Weekly delivery from stores to the assembly line ➢ Daily order from production control to stores ➢ Monthly customer order placed for the galley ➢ Monthly orders being fulfilled and delivered to the customer
Assign	➢ Assigning "Tnow" in order to calculate time in system ➢ Assigning entity pictures
Station	➢ Points in model to which entities are transferred
Process	➢ Intended as the main processing method in the simulation ➢ Seize, delay and release the product
Route	➢ Transfer the entity to the destination station specified
Decide	➢ Allows for the decision-making processes in the system
Record	➢ Collect count type and interval statistics in the simulation model
Request	➢ Assigns a transporter unit to an entity and moves the unit to the entity's location
Transport	➢ Transfers entity to a destination station
Free	➢ Release the entity's most recently allocated transporter unit
Dispose	➢ Ending the model, when the order is delivered to the customer

Table 7 Animation used in the model

Resource	Animation	
	Busy	Idle
Assembly line workers		
Inspection workers		
Packing worker		
Transporter	**Animation**	
	Busy	**Idle**
Delivery Trolley		
Production Control Paper		
Order		
Monthly output		

11.4.2 Description of the model

The simulated process for the current state value stream map of the galley assembly line starts off with the customer placing a monthly order. This can be viewed in the top right hand corner of the current state simulation model. Please refer to figure 19 for the dynamic value stream map. The weekly delivery from the stores to the assembly line takes place and is illustrated by Figure 15. Figure 16 illustrates how the production department communicates with the stores on a daily basis. The customer order that is communicated to the production department at Aerosud is illustrated in Figure 17.

Raw material is created according to the customer order schedule until December 2009 and arrives at the NC Cutting station. The order schedule can be viewed in Appendix D. This section of the model can be viewed in figure 18. The material are then assigned a "Tnow" value (attribute) in order to initiate the time in system variable. The material is also assigned an entity picture. The raw materials then seize the NC Cutting worker for processing. The times of the process is similar to the time displayed in the current state value stream map. The panels are then routed to the bonding cell. The entity pass through the bonding and décor cell in the similar manner as described for the NC Cutting cell. This part of the model can also be viewed in figure 18.

Figure 15 Transporter Logic

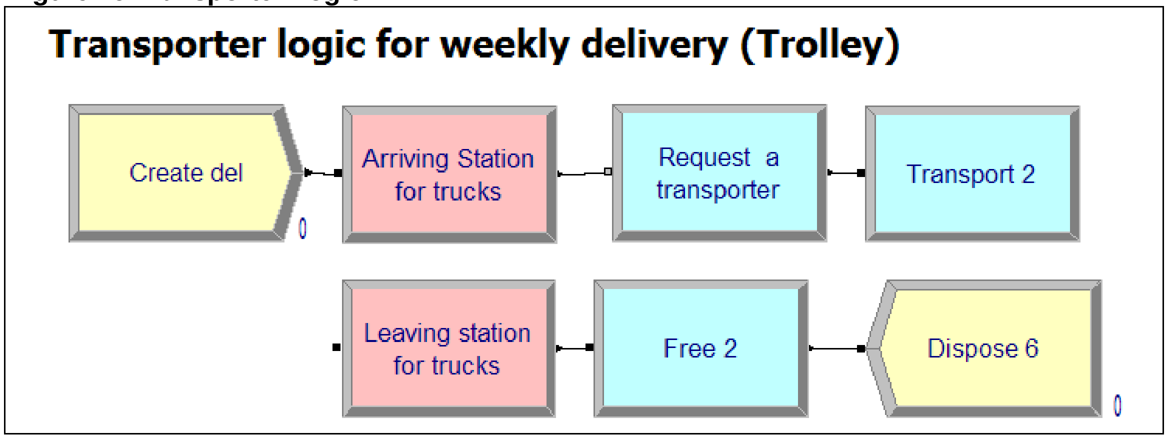


Figure 16 Production Logic

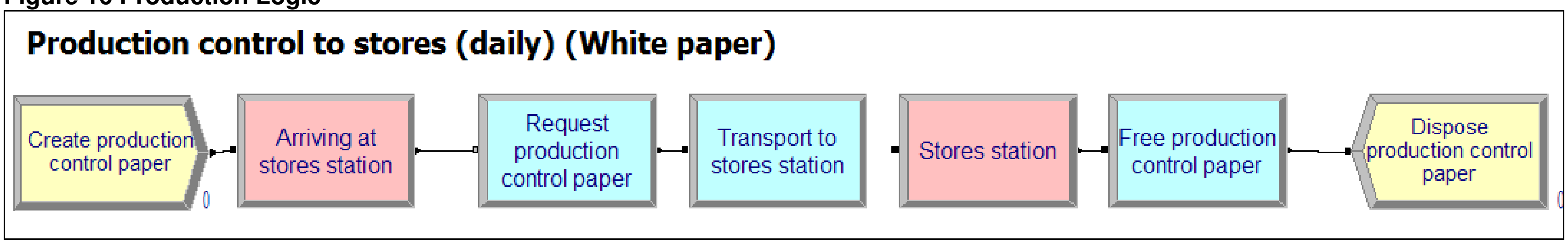


Figure 17 Monthly customer orders

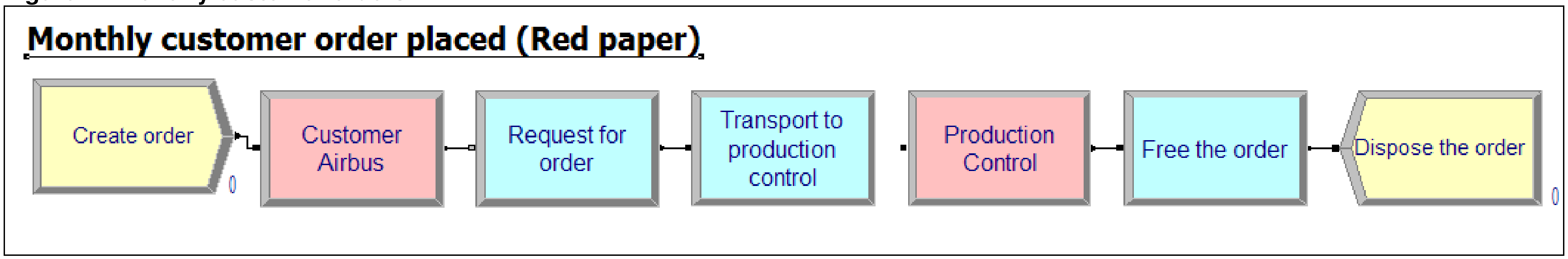


Figure 18 NC Cutting, Bonding and Decor

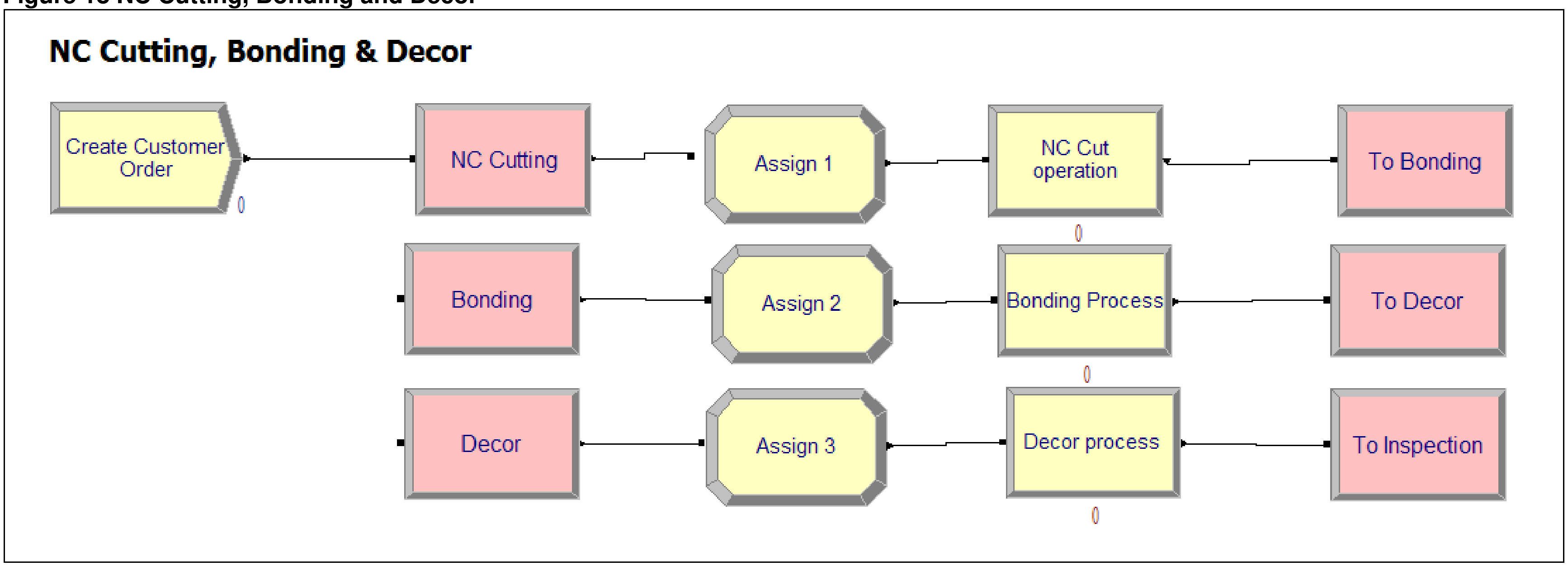
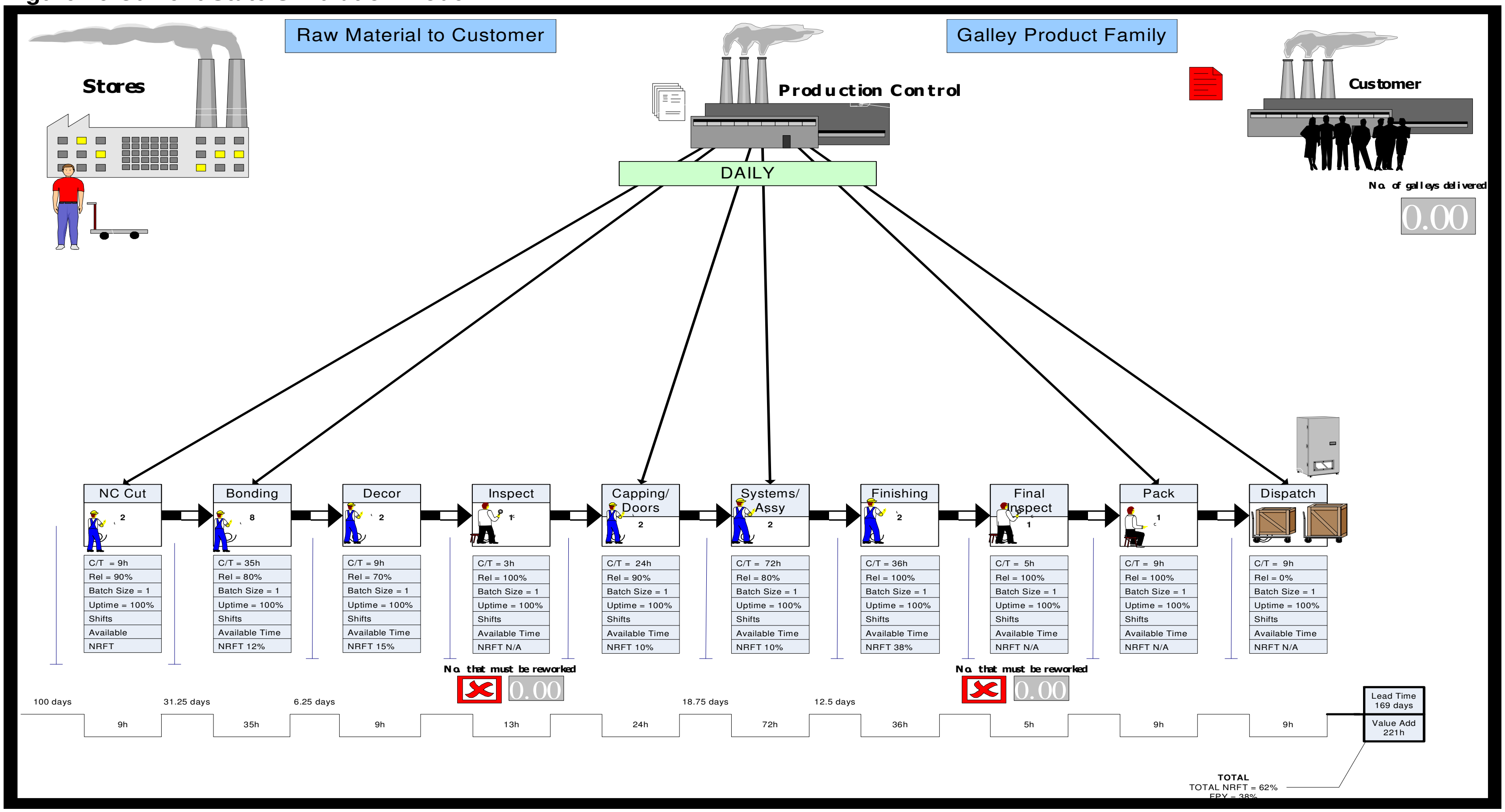


Figure 19 Current State Simulation Model



After the Décor cell, the first inspection takes place. The parts are then assigned a new entity picture. The parts then seize the inspector for processing. There are three different outcomes for the inspection process. If inspection is passed by the parts, it is recorded and the parts are routed to the capping cell. If the parts have some minor defects that can be repaired, the parts is delayed and then routed back to the bonding cell to repair the problem. Only in really severe cases will a part be scrapped. Scrapping is only considered if the damage to the parts is in repairable. The part that is scrapped will be delayed and then disposed out of the system. Figure 20 illustrates the inspection cell operations.

After inspection the partially assembled galley enters the capping cell. A new entity picture is assigned to the galley. The galley then seizes capping worker for processing. The process times is displayed in the current state value stream map. The parts are then routed to the systems cell. The entity pass through the systems and finishing cell in the similar manner as described for the capping cell. This part of the model can be viewed in figure 21.

After the finishing cell, the fully assembled galley is routed to the final inspect cell. Here the final inspection of the galley takes place to make sure the galley complies with customer specification. The final inspection process is a tedious process and takes five hours. The completed galleys are assigned a new entity picture and continue to use the inspection worker for processing. The different outcomes are the same as for the first inspection process mentioned above. The fully inspected galley is then routed to the packing cell where the galley it is wrapped and packed before being dispatched to the customer. The last station in the simulation model is the dispatch cell. It is from this cell that the final assembled galley is dispatched to the customer. The time in system and the amount of galleys shipped is recorded before disposal. These sections can be viewed in figure 22 and figure 23. Figure 23 also shows the completion of monthly orders.

Figure 20 Inspection

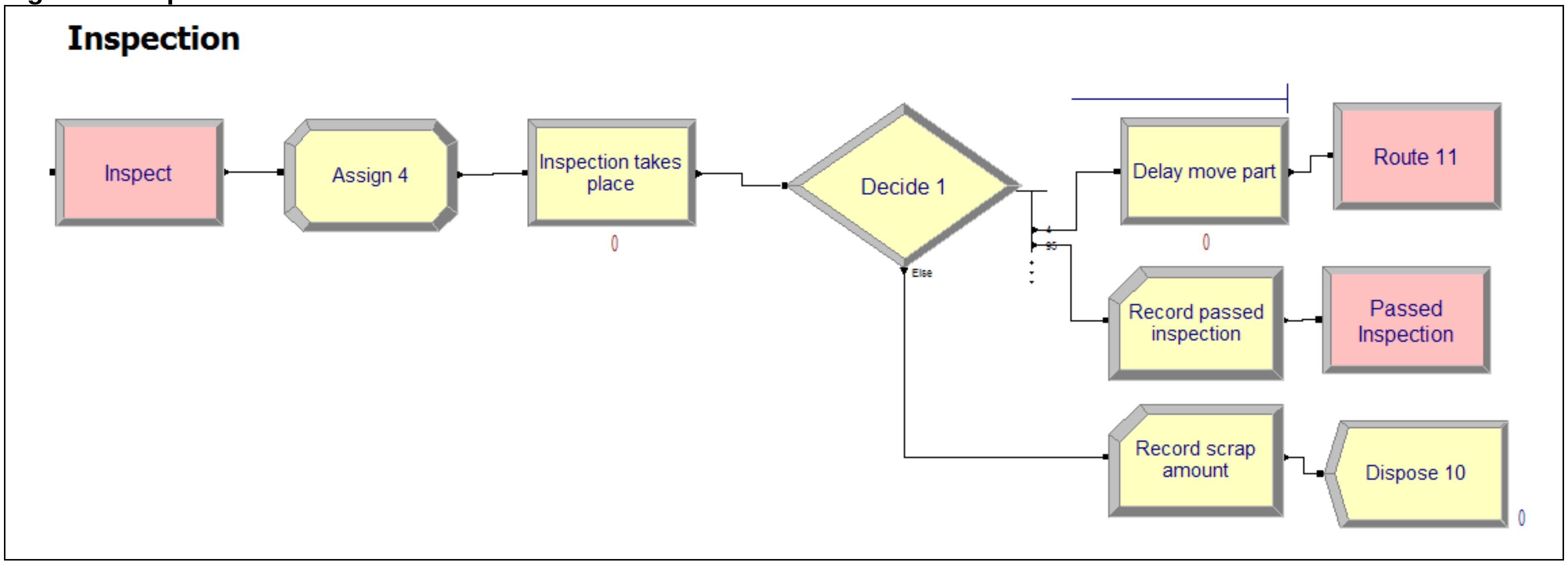


Figure 21 Capping, Systems and Finishing

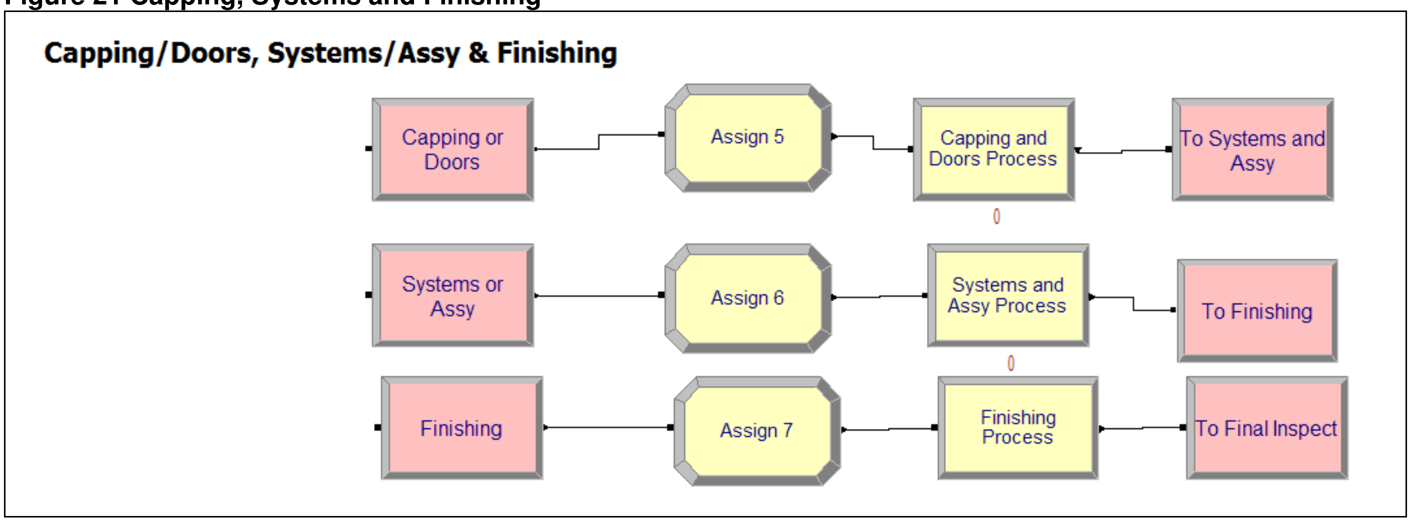


Figure 22 Final Inspection

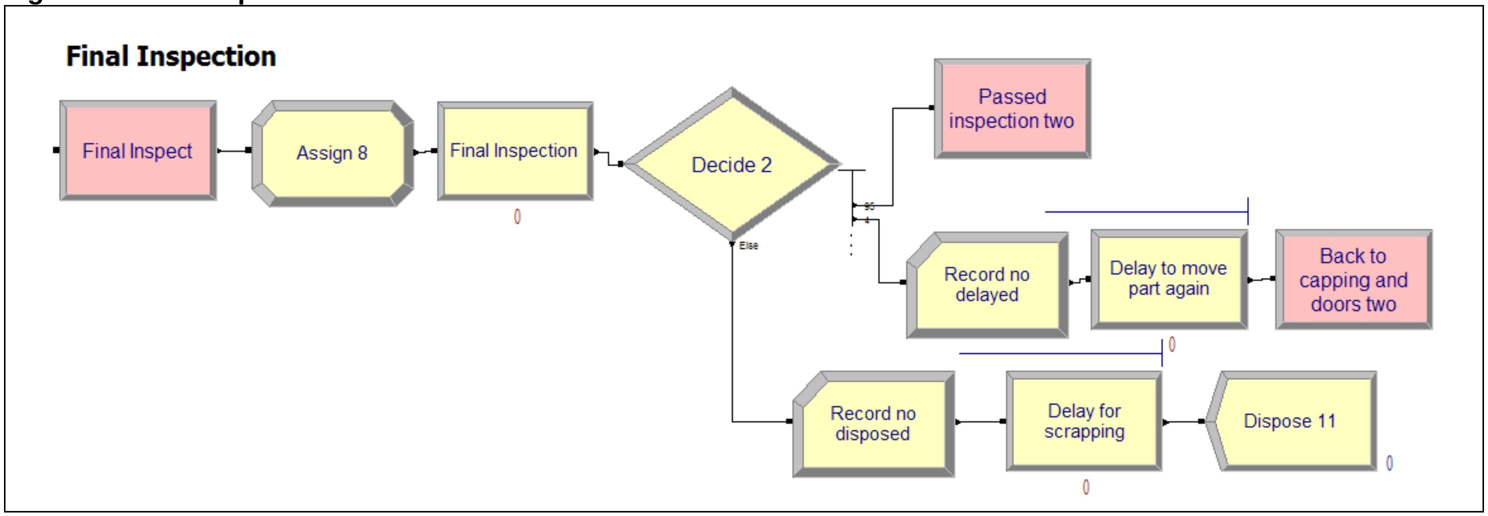
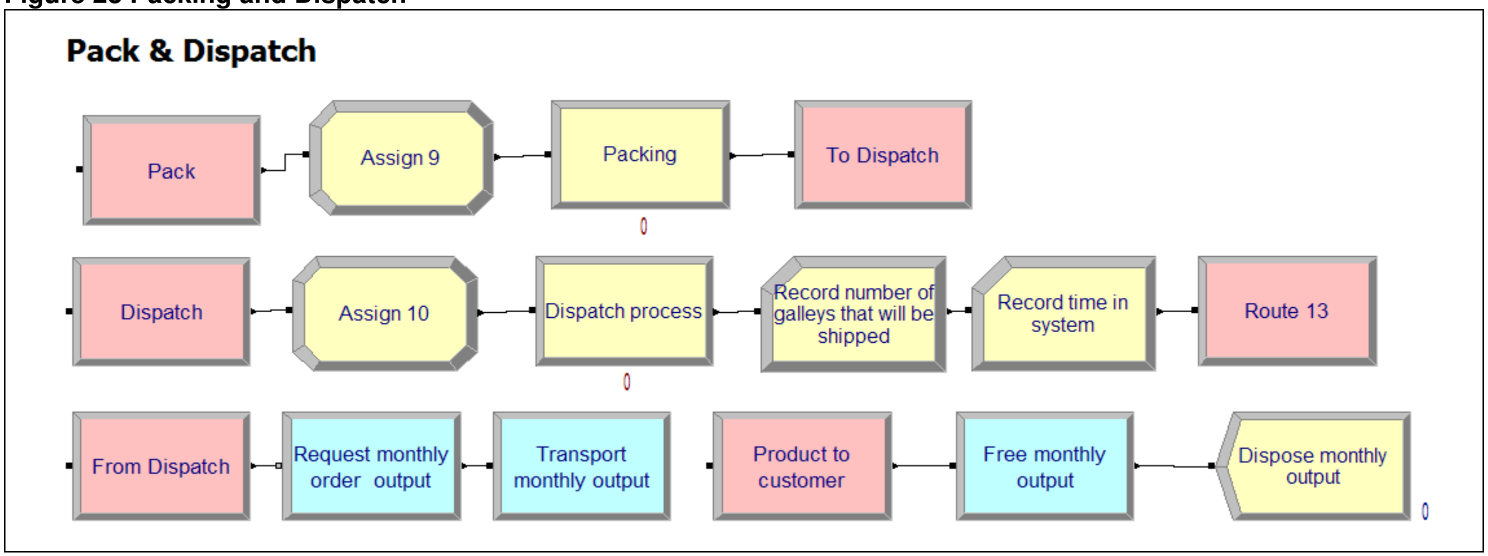


Figure 23 Packing and Dispatch



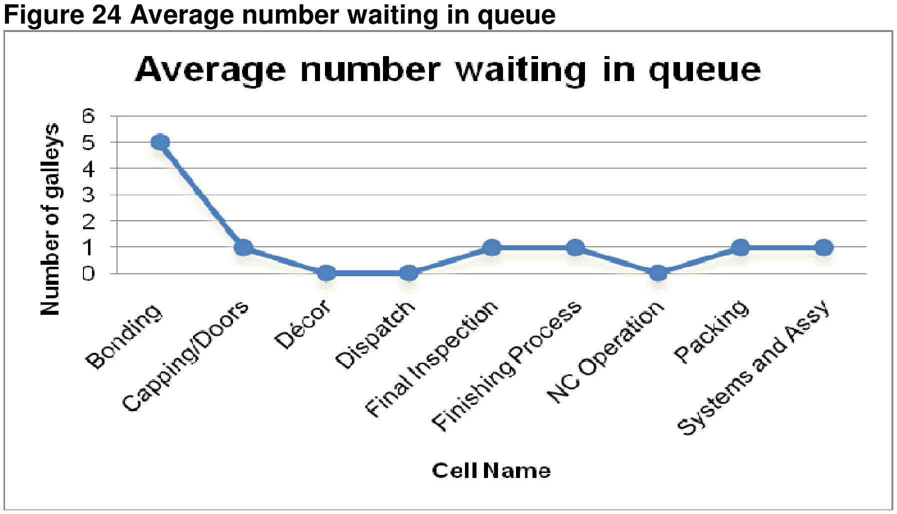
11.4.3. Current State Simulation Model Results

The model was run for twenty replications where each replication represented 250 days. The value-added time and waiting time of the parts in the system were measured. Chase et al (2004) describes value-added time as the time in which useful work is actually being done on a part. The output of the model is summarized in Table 8. The number of galleys delivered to the customer was 40.The current state model can be used to get the most desirable future state by testing different scenarios. The average number of parts waiting in the queues of the different cells where compared in Figure 24, and it clearly shows that the Bonding cell is the bottleneck in the assembly line. The simulation aided value stream mapping approach (saVSM) identified the bonding cell as the actual bottleneck, where the value stream map alone didn't show it. The bottleneck analysis will be focused on the bonding cell.

Table 8 Current State Model output

Cell Name	Average Value- added Time per enitity (in days)	Average Waiting Time per enitity (in days)
Bonding	3	0.6695
Capping and Doors	1	0.00004324
Décor	0.375	0
Dispatch	0.375	0
Final Inspection	0.2083	0.00009388
Finishing	1.5	0.00288627
First Inspection	0.125	0
NC Cutting	0.375	0
Packing	0.375	0.00041667
Systems and Assy	1.4583	0.02412473

Figure 24 Average number waiting in queue



12. Design and Problem Solving

The aim of this project is to improve productivity that in return will have a positive effect on profit and create continuous flow. With all the relevant data and information collected concerning the above mentioned areas, problem solving can commence. The first step is to develop a future state value stream map. This will be followed by comparing the current and future state maps and identifying the bottleneck in the assembly line. The focus will then shift to improving operations, flow, layout improvement and finally trade-off analysis and financial impact of improvements.

12.1 Future State Value Stream Map

The future state value stream map represents the most optimal state that the assembly line operates in. A few changes occurred from the current value stream map mentioned earlier. The method to construct the future state value stream map figures falls outside the scope of the project, and therefore will not be discussed. Please refer to Appendix C for an explanation of the value stream mapping icons. The future state value stream map can be viewed in Figure 25. There are only seven operations included in the value stream map. Two supermarkets where created, one at the bonding cell and the other one at the capping and doors cell. A supermarket is a control inventory of parts that is used to schedule production at an upstream process. The formula for the calculation of takt time was discussed in Section 8.7. The takt time has been reduced from 6.25 days to 4.17 days per galley. To recall takt time, or better known as the heartbeat of production, is the rate at which parts must be produced to satisfy the demand. Table 9 summarizes the differences between the current state of the assembly line and the new improved state.

Table 9 Comparing Current and Future State

Measure	Current State	Future State	Improvement
Lead Time	169 days	30 days	139 days
Value Adding Time	221 hours	139 hours	82 hours
Takt Time	6.25 workdays/galley	4.17 workdays/galley	2.08 workdays/galley

There is a wide variety of information that is displayed on a value stream map. Table 10 summarises the data of the ideal future state of the galley assembly line. The definitions for the value stream mapping components are the same as discussed in Section 11.2.

Figure 25 Future State Value Stream Map

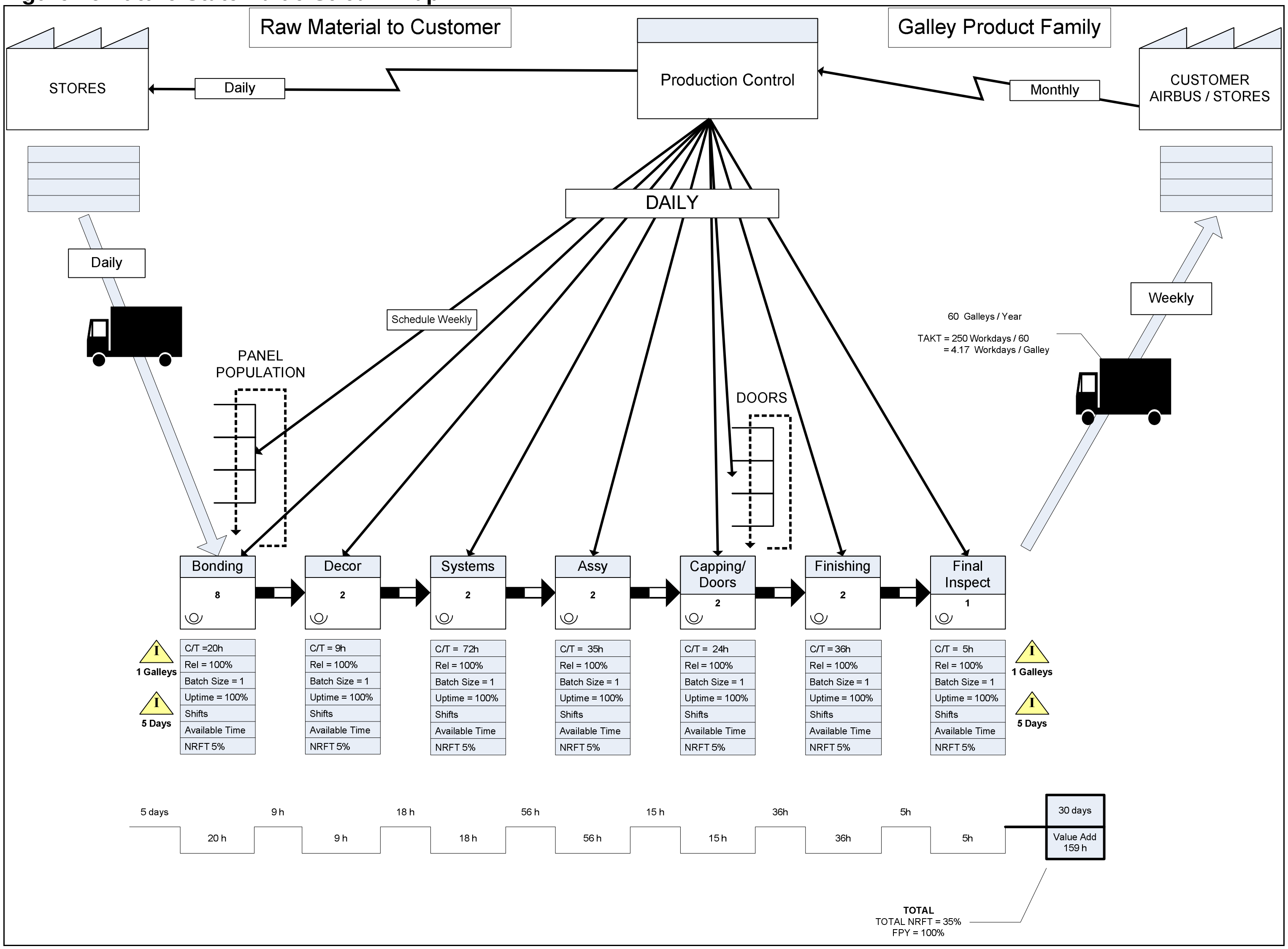


Table 10 Future State Value Stream Map Information

Cell	Cycle Time	No. of workers	Reliability	Not Right First Time (NRFT)	Value Added Time	Lead Time
Bonding	20h	8	100%	5%	20h	5days
Decor	9h	2	100%	5%	9h	9days
Systems	72h	2	100%	5%	18h	18days
Assy	72h	2	100%	5%	56h	56days
Capping/Decor	24h	2	100%	5%	15h	15days
Finishing	36h	2	100%	5%	36h	36days
Final Inspect	5h	1	100%	5%	5h	5days

12.2 Future State Simulation Model

A simulation model was built using Rockwell's Arena 7.01 and was created to resemble the operations involved in the future state of the galley assembly line. The primary objective of the simulation models were to provide an interactive dynamic value stream map where to verify outcomes to different changes to the assembly line and be able to visually see the effect of the changes on the assembly line. The assumptions mentioned in Section 11.4 are also applicable to this model.

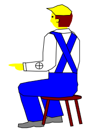
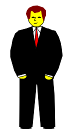
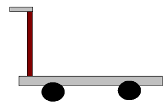
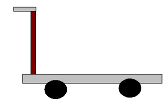
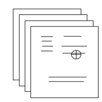
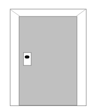
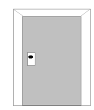
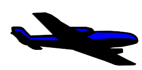
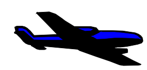
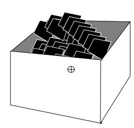
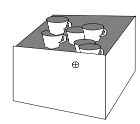
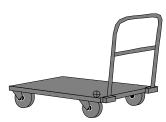
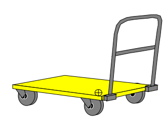
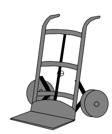
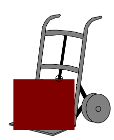
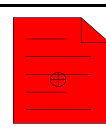
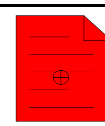
12.2.1 Pieces of the simulation model

The simulation model for the future state value stream map was built using the basic building blocks in Arena. The main objective was to resemble the value stream map in a dynamic form. The simulation model consists of the same parts as mentioned in Section 11.4.1. Table 11 summarizes the building blocks that were used to simulate the above mentioned pieces of the model. Furthermore, the animation used in the model can be viewed in Table 12.

Table 11 Building Blocks of the future state simulation model

Building Block	Description
Create	Panel movement from the panel supermarket to bonding cell Panel movement from stores to the supermarket Material movement from stores to bonding cell Door movement from the supermarket to capping cell Daily order from production control to stores Monthly customer order placed for the galley Orders creation for the bonding cell Material movement from stores to capping cell
Assign	Assigning “Tnow” in order to calculate time in cell and system Assigning entity pictures
Station	Points in model to which entities are transferred
Process	Intended as the main processing method in the simulation Seize, delay and release the product
Route	Transfer the entity to the destination station specified
Decide	Allows for the decision-making processes in the system
Record	Collect count type and interval statistics in the simulation model
Request	Assigns a transporter unit to an entity and moves the unit to the entity’s location
Transport	Transfers entity to a destination station
Free	Release the entity’s most recently allocated transporter unit
Dispose	Ending the model, when the order is delivered to the customer
Signal	Signaling when the supermarket must be refilled with stock

Table 12 Animation used in future state model

Resource	Animation	
	Busy	Idle
Assembly line workers		
Inspection workers		
Transporter	**Animation**	
	Busy	**Idle**
Trolley		
Production Control Paper		
Door Cap		
Monthly output		
Delivery Trolley		
Panel Trolley		
Door Mover		
Order		

12.2.2 Description of the future state model

The simulated process for the future state value stream map of the galley assembly line starts off with the customer placing a monthly order. This can be viewed in the top right hand corner of the future state simulation model. Figure 26 shows the customer order that is communicated to the production department at Aerosud. Refer to Figure 27 for the dynamic future state map. The daily communication between the production department and the stores can be viewed in Figure 28. The delivery from the stores to the assembly line takes place and is illustrated by Figure 29.

Raw material is created according to the customer order schedule until December 2009 and arrives at the bonding station. The NC Cutting operation is not included in the future state value stream map. The order schedule can be viewed in Appendix D. The raw material that is received is already cut according to specification by the supplier. The material are then assigned a "Tnow" value (attribute) in order to initiate the time in system variable. The incoming material is also assigned an entity picture. The raw material then seizes the bonding workers for processing. The time in the cell is similar to the time displayed on the future state value stream map. The panels are then routed to the décor cell. The entities pass through the décor, systems, assembly, capping and finishing cell in the similar manner as described for the bonding cell. These sections of the model can be viewed in Figure 30 and Figure 31.

After the Finishing cell the inspection of the galley takes place. The parts are then assigned a new entity picture and then seize the inspector for processing. There are three different outcomes for the inspection process. If the material passed the inspection it is recorded and the material is transported to the customer. If the parts have some minor defect that can be repaired, then the material is delayed and then routed back to the bonding cell to repair the problem. Only in really severe cases will the parts be scrapped. The material that is scrapped will be disposed out of the system. The inspection process can be viewed in Figure 32. There are two supermarkets present in the future state map. To model this, signal logic was used to resemble the process of the supermarket filling up as the material is used by the assembly line. This will ensure that there is always raw material available for the assembly line to use. Refer to Figure 33 and 34. The movement from the supermarkets to the assembly line are animated using transporters and can be viewed in Figure 35 and 36.

Figure 26 Future State Monthly customer order

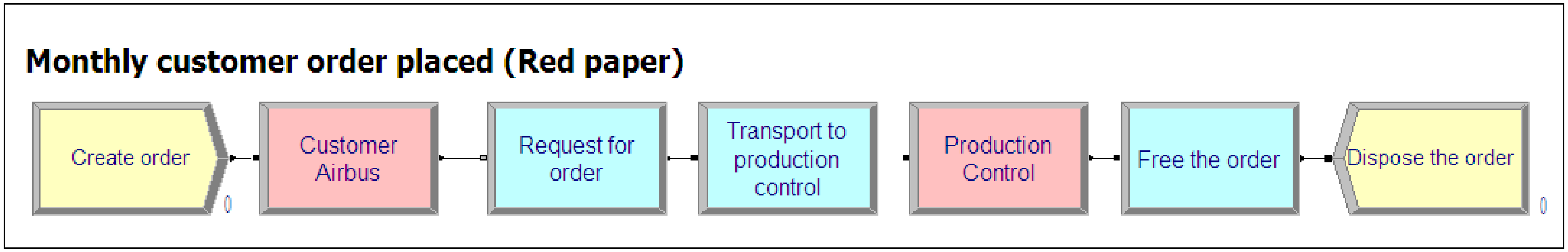


Figure 28 Daily production control

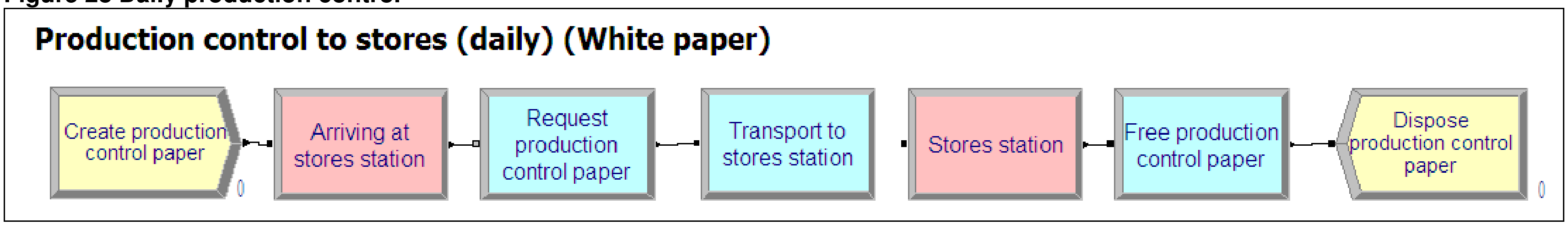


Figure 29 Delivery to assembly line

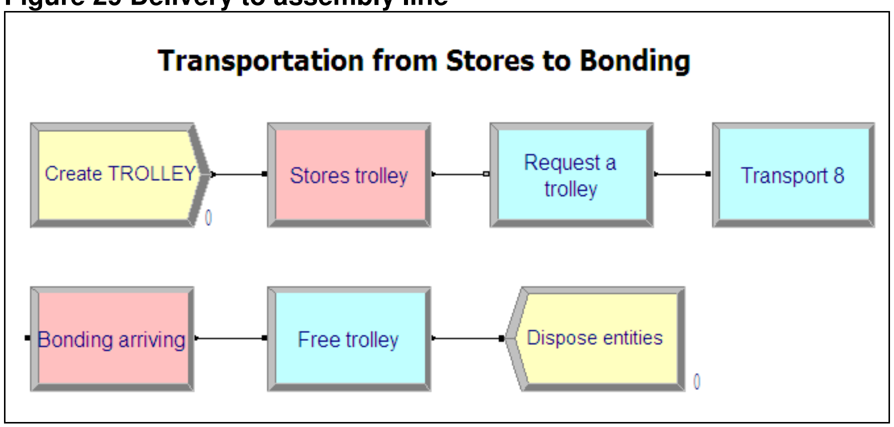


Figure 30 Bonding, Décor and Systems cell operations

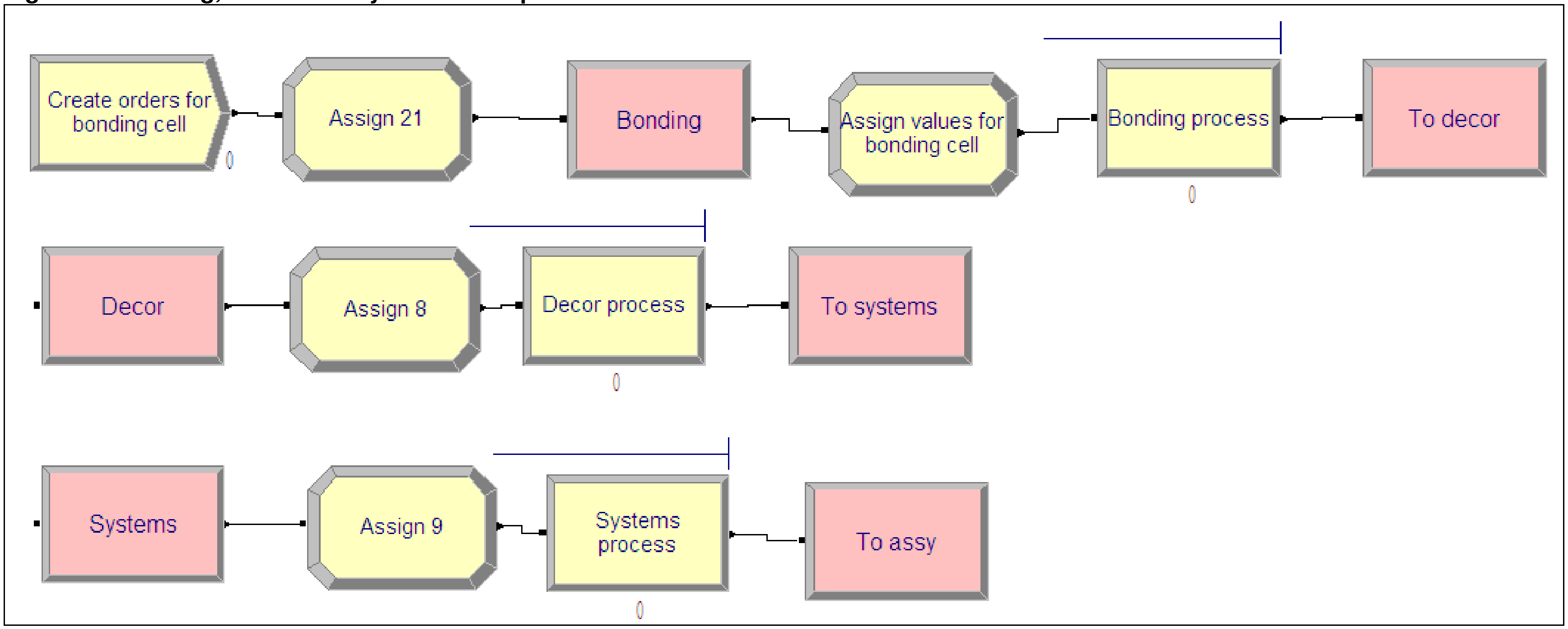


Figure 31 Assembly, Capping and Finishing operations

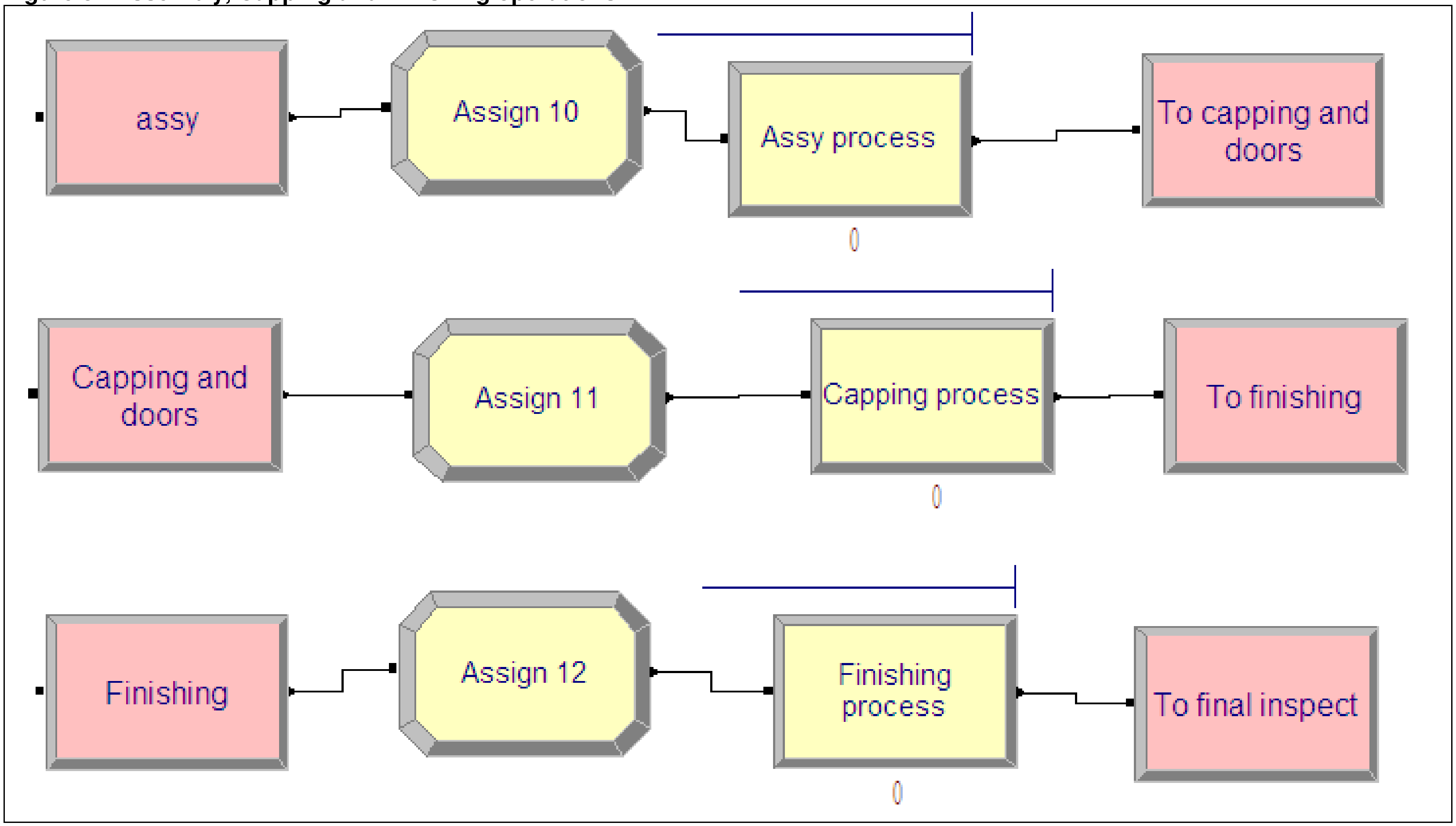


Figure 27 Future State simulation model

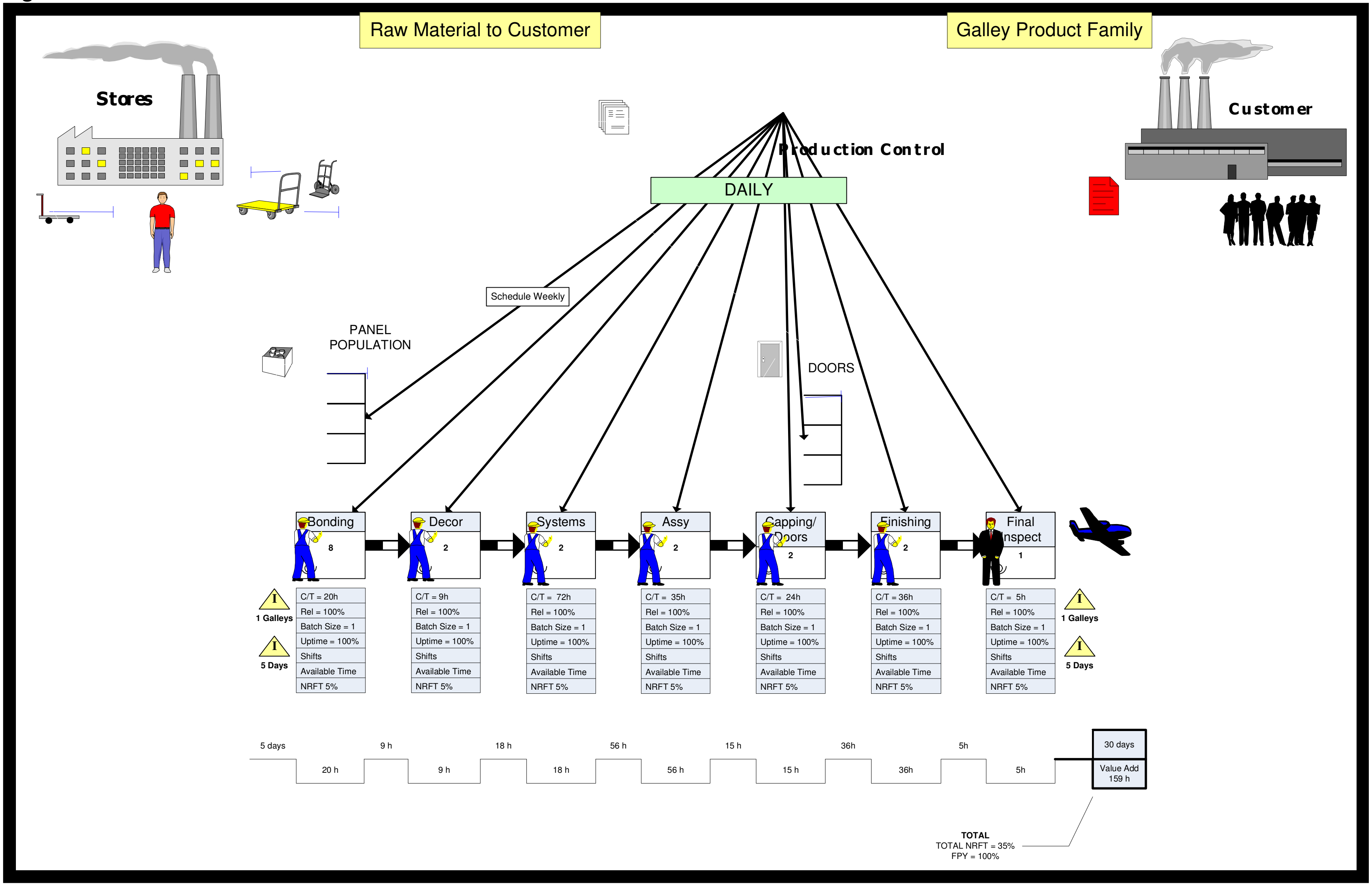


Figure 32 Inspection process

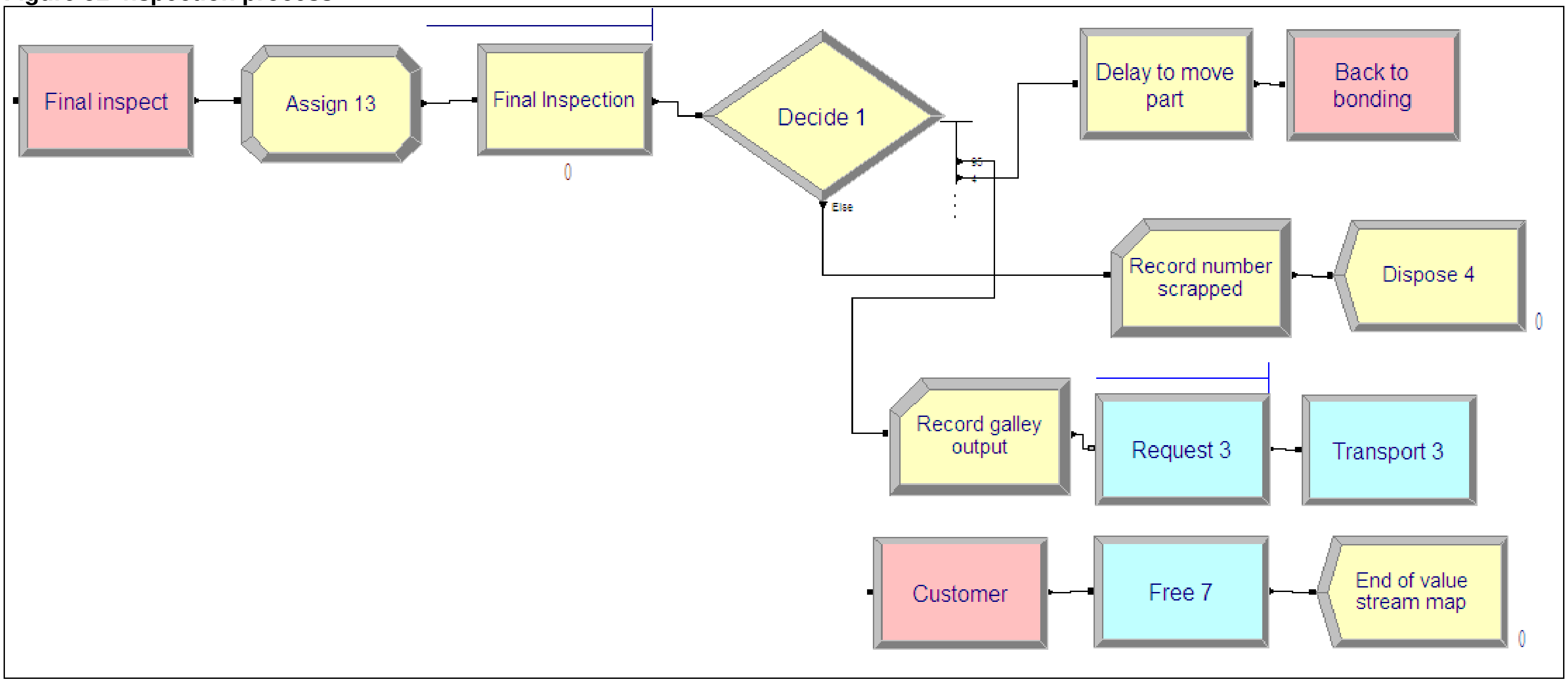


Figure 33 Panel Supermarket

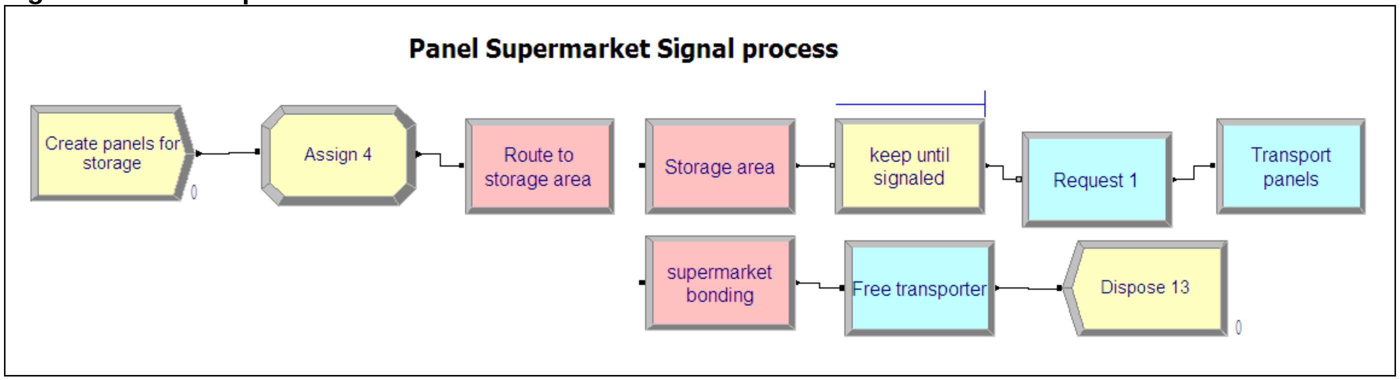


Figure 34 Door Supermarket

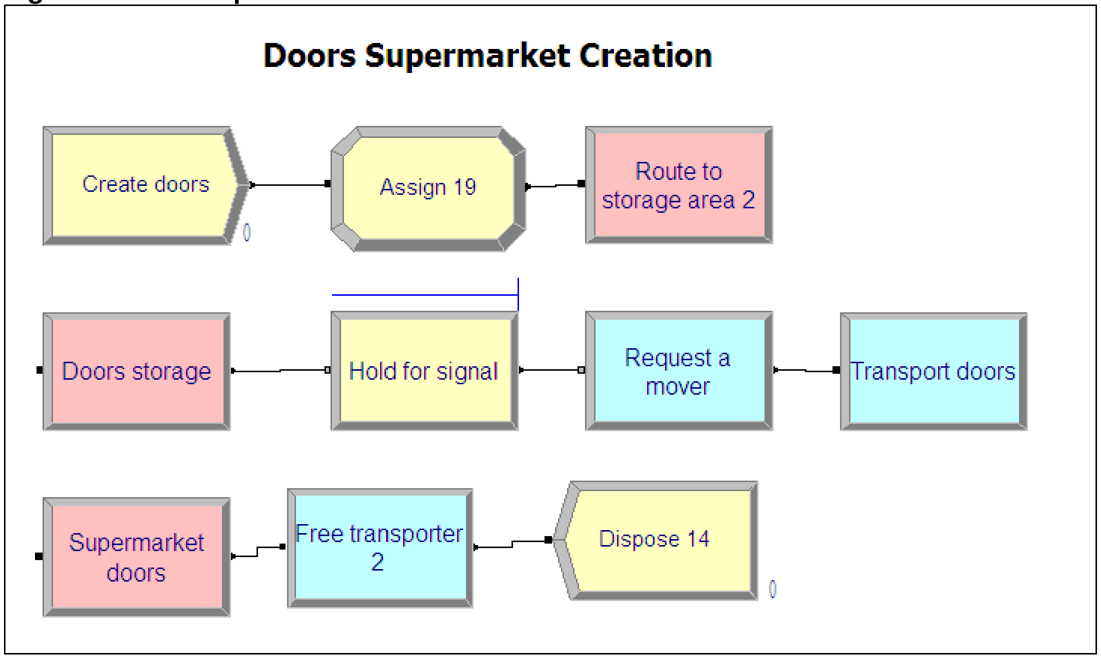


Figure 35 Movement from doors supermarket to the capping cell

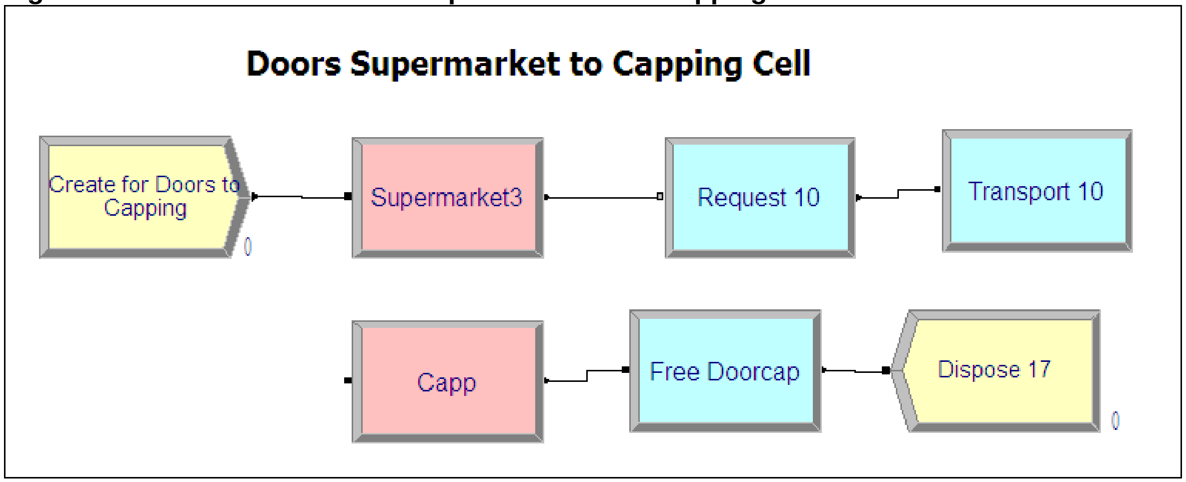
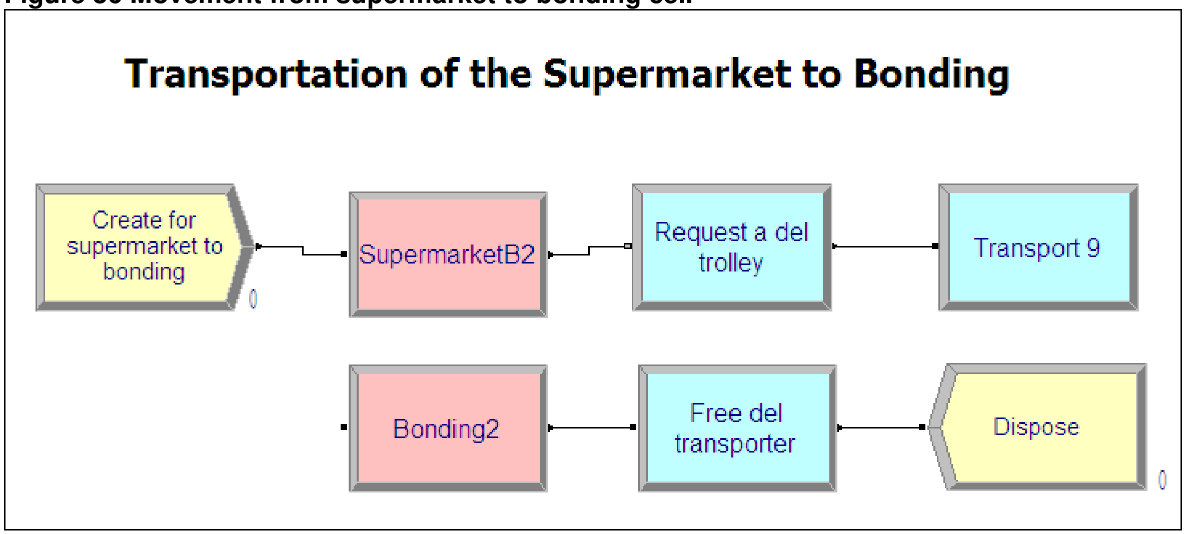


Figure 36 Movement from supermarket to bonding cell



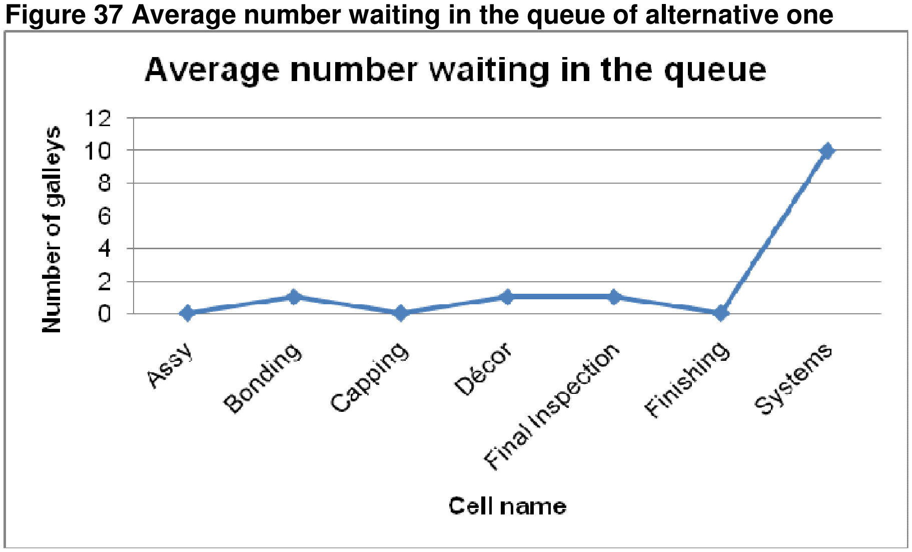
12.2.3 Alternative one – Proposed Future State

The model was run for twenty replications where each replication represented 250 days. The value-added time and waiting time of the parts in the system were measured. The output of the model is summarized in Table 13. The number of galleys that was delivered to the customer was 60. The simulation of the future state map identified a number of problems. The number of days a galley will spend waiting in a queue at the systems cell is 38.1148 days. This will create a lack of continuous flow in the assembly line. The galley line won't be able to accommodate all the galleys because of a lack of space. The average number of parts waiting in the queues of the different cells where compared in Figure 37. The average number of galleys in the systems queue is ten. A bottleneck is now created at the systems cell. This only showed once the value stream map was combined with simulation modelling. The value stream map alone didn't predict any problems.

Table 13 Proposed Future State Model Output

Cell Name	Average Value- added Time per enitity (in days)	Average Waiting Time per enitity (in days)
Bonding	0.8333	1.6187
Capping and Doors	1	0
Décor	0.375	2.5725
Final Inspection	0.2083	0.0828845
Assy	1.4583	0
Finishing	1.5	0
Systems	3	38.1148

Figure 37 Average number waiting in the queue of alternative one



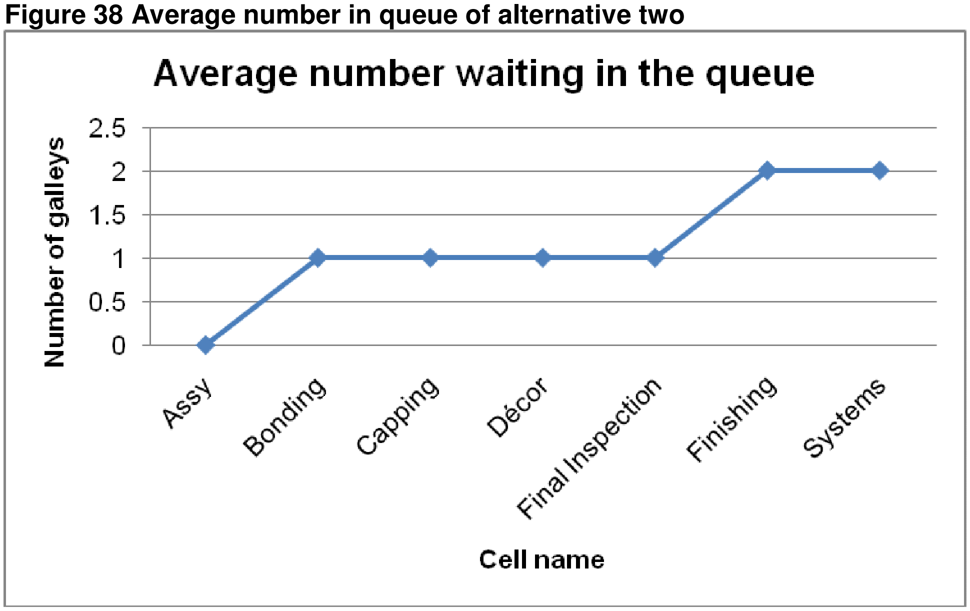
12.2.4 Alternative two – Improved Future State

The results generated by the proposed future state map is not the optimal solution, therefore an improved future state value stream map will be evaluated. The improved cycle time (C/T) of the systems cell has been reduced to 36 hours and have been entered into the model. The amount of workers in the assembly and systems cell were doubled to see the impact it will have on the assembly line. Table 14 summarises the output of the model. The average waiting time per entity in the systems cell queue have been reduced by 33 days. The waiting times in the Capping and Finishing cell queues increased by four and eight days. The number of galleys that was delivered to the customer was 60. The average number in the queue in front of the systems cell was reduced to only two galleys and can be viewed in Figure 38. The results show that the bottleneck at the systems cell has been improved and the same amount of galleys were delivered to the customer in 250 days.

Table 14 Improved Future State Model output

Cell Name	Average Value- added Time per enitity (in days)	Average Waiting Time per enitity (in days)
Bonding	0.8333	1.611
Capping and Doors	1	3.8224
Décor	0.375	2.5656
Final Inspection	0.2083	0.08212322
Assy	1.4583	0
Finishing	1.5	7.3105
Systems	1.5	5.2236

Figure 38 Average number in queue of alternative two



12.2.5 Financial Implications of Improvements

The financial implications of the current state, alternative one and alternative two are compared in Table 15. The profits were calculated using the Excel spreadsheet that was discussed in Section 11.3.

Table 15 Financial Implications

Scenario	Total profit per month	Total profit per shipset	Total profit per year
Current state	-R 562,463.00	-R 255,665.00	-R 6,749,556.00
Proposed future state (Alternative 1)	R 1,434,528.00	R 286,906.00	R 17,214,337.44
Improved future state (Alternative 2)	R 1,260,534.00	R 252,107.00	R 15,126,408.48

It is clear that there are a lot of other improvement opportunities on the galley assembly line. The cycle time of the galleys is just one of many areas, but resulted in a significant improvement with regards to time savings. Alternative two produced less profit than alternative one because of the amount of workers that was increased on the galley assembly line in order to reduce the cycle time per cell. Labour cost plays a significant part in the calculation of the profit on the assembly line.

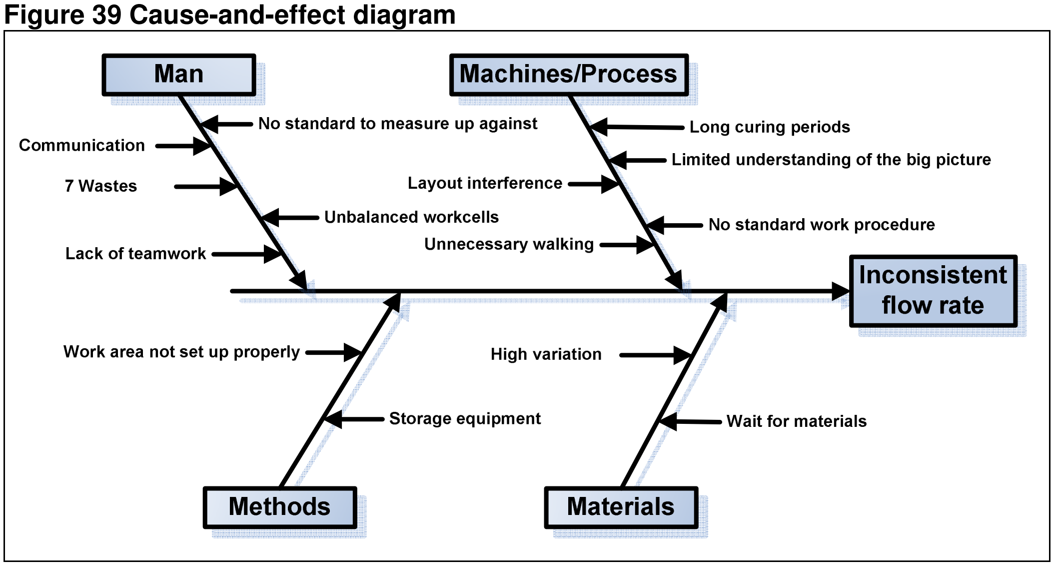
12.3 Bottleneck identification

The value stream mapping process starts by drawing up a current state value stream map. The current state value stream map assists in understanding how the area currently operates. The future state map is designed for lean flow and resembles the process potential. After the future state map, it is necessary to have a work and implementation plan. There must be planned how to move from the current state to the desired future state and execute the plan. To aid in the execution of the plan, the bottleneck of the galley assembly line was identified as the bonding cell. Because the bonding and décor cell are currently part of the same cell area the improvement process will be focused on the bonding and décor cell. The focus of the improvements will be to improve the current state of operations.

12.3. 1 Problem identification

To eliminate the bottleneck in the assembly line, a continuous flow rate must be created the cell. In order to create a continuous flow rate a thorough analysis needs to be done on the major causes for the lack in flow. It was established that the process flow rate can be influenced by the four production inputs, better known as the 4M's, i.e. material, man, methods and machines/processes. The main causes to the inconsistent production flow rate in the bonding cell can be summarized using the cause-and-effect diagram (fishbone diagram), as indicated in Figure 39.

Figure 39 Cause-and-effect diagram



The actions that will be performed to solve the identified problems in the bonding and decor cell are:

- Understand general cell operations
- Perform time and work studies
- Develop standard operating procedures (SOP)
- Apply the critical analysis technique (5W1H)
- Layout recording and improvement
- Flow diagrams of proposed and current layout
- Create simulation model of bonding cell
- Trade off analysis between different improvement ideas using simulation modeling
- Financial implications of improvements

12.3.2 General Cell Operations

The bonding process is started when precut panels are received from the cutting cell. Inspections of the panels take place to verify the size and quality. Inserts are bonded into the precut holes in the panel and left to dry for a period of eight hours. Afterwards excessive glue is removed from the panel and the panel undergoes another inspection. This is again only a visual inspection to make sure that the bonded inserts adhere to the strict customer specification.

The dry fitting process can be described as fitting the panels and taping them together to form a complete galley. Dry fitting of the panels is extremely important because the worker must be absolutely sure that the different panels fit together before the bonding process starts. After the panels are dry fitted, the whole galley is taken apart and potting is applied to the side panels to seal them. The potting is then squared using a trowel or file. The bonding process is the most labour intensive process in the whole assembly line. The reason for this is because there are so many tasks that need to be performed. The breakdown of the different tasks involved can be viewed in Appendix E. It is important to use exactly the right amount of glue to bond the galley. Therefore a scale is used to weigh the different ingredients. Again the glue needs eight hours to dry. The excessive glue is then cleaned with a chemical and the sides are sealed.

Spreader plates and squares are then attached to the galley. The attachment process involves preparation, bonding and cleaning of the spreader plate and square. While the spreader plates are drying the rest of the attachments can be fitted, bonded and cleaned. After all the attachments have dried the different subassemblies are bonded together and again left to dry for eight hours. This is followed by the final finishing and inspection of the galley before it moves on to the capping and doors cell. The drawers of the galley are also assembled in the bonding and décor cell. The same processes as for the galley are followed; the only difference will be the time per process. The complete process flow breakdown of the bonding and décor cell can be viewed in Appendix E.

12.3.3 Work and time studies

In order to be able to completely understand the process and to detect where time is wasted and where improvements can be made, work- and time studies are extremely important. Historical data of the bonding cell was available but it was outdated and only consisted of estimates. This meant that all the data required had to be captured by means of time studies. Limited data on the current process flow and standard operating procedures of the bonding cell were available. This required thorough analysis of the operations in the bonding cell.

Time studies of each process in the bonding cell were captured, from when the raw material enters the cell up to where the partially completed galley leaves the cell. The process times can be viewed in Appendix F. The data that was captured will be used to create a simulation model that reflects reality as will be discussed in Section 12.3.7. The data will be used for various other reasons as well.

One of the biggest problems that management at Aerosud face is the fact that a galley design will change regularly. The time study data collected earlier will then no longer be accurate. A model in Excel was developed to translate any galley design into time units. The model will help management to accurately calculate the time a galley will spend in the bonding and décor cell. The time study data mentioned earlier where used to make the calculations. This model will also be used to feed data into the simulation model which will be discussed in Section 12.3.7. The model enables the user to select the number of plates, inserts and sides in the design. The number of attachments and many more items can be edited. The amount selected is then multiplied with the time it will take to perform a single selected operation. Once all the criteria are selected, the total time that the galley will spend in the bonding and décor cell is provided back to the user, which will be helpful with production planning.

In Table 16 a part of the model is shown. For this example, a galley with 23 inserts and 1.3 m of potting is assembled. This specific galley will spend 34.65 hours in the bonding and décor cell. The total time is calculated in seconds and then converted to hours and are summarized in Table 17 to 21.

Table 16 Excel Data Model

Galleys

Step 1:	Inspection of plates			
How many plates?	13		Time	3900
Step 2:	Inserts			
How many inserts in design have?	23		Time	920
Step 3:	Inspection of plates			
How many plates?	13		Time	3900
Step 4:	Potting process			
How many meters need potting?	1.3		Time	46.618
Step 5:	Square of potting			
How many meters need to be squared?	1.2		Time	0.36
Step 6:	Bonding			
How many cups of glue needed?	3		Time	1620
How many long sides to apply glue for?		16	Time	1584
How many short sides to apply glue for?		12	Time	508.32
How many intermediate sides to apply glue for?		24	Time	2102.4
How many slots to fill up with glue?		18	Time	22.68
How many sides need finishing touches?		2	Time	162
Step 7:	Cleaning and sealing			
How many sides need cleaning & sealing?		13	Time	1739.4
Step 8:	Attaching squares & spreader plates			
How many spreaders in design?		9	Time	9726.93
Step 9:	Cleaning and sealing of spreader plates			
How many spreaders?		4	Time	710.4
Step 10:	Attachments			
How many attachments need to be measured out?		9	Time	72
How many attachments need to be bonded?		9	Time	3780

Table 17 Excel model part two

Total Time for galley without drawers	
Total Step1 to Step 10 (in seconds)	30795.108
Conversion to minutes	513.2518
Conversion to hours	8.5541967

Table 18 Adding curing times

Adding curing times * 2 (time in hours)	24.554197
Adding dry fitting prep + dry fitting time	26.077197
Dry fitting times now added	26.647197

Table 19 Adding Subassemblies

Separate subassemblies bonded together		
How many sides need cleaning & sealing?	11	Time 24.53
Time conversion to minutes		0.4088333

Table 20 Subassemblies bonded

Total time of subassemblies bonded together to form galley (1x curing time added) (time in hours)	34.654011

Table 21 Total time calculation

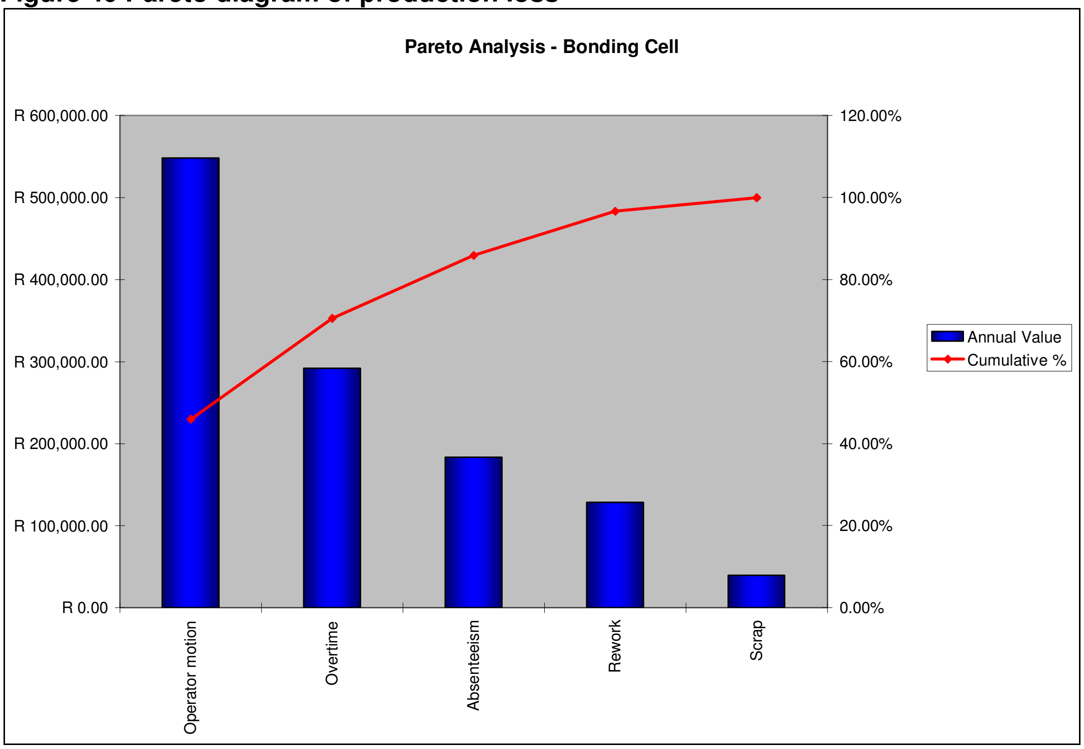
Total time of galley in bonding & décor cell without drawers (in hours)	**34.654011**

12.3.4 Standard Operating Procedures (SOP)

Limited data were available on what the duration of the different processes were and employees working on the shop floor did not know what the standard of work was that was expected from them.

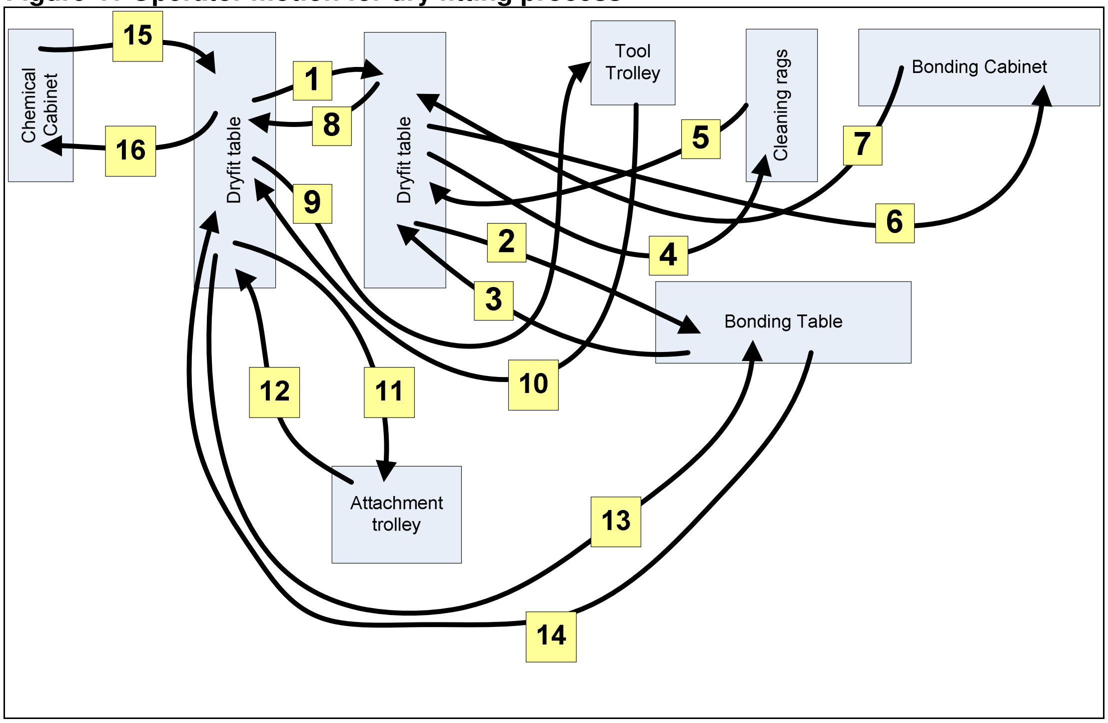
Due to the fact that none of the employees on the shop floor knew what they were capable of doing and what production of work was expected from them, the process time per part varied a lot. Once too much variation takes place, continuous flow will be unsustainable. In order to identify the reasons that are responsible for the most production loss in the bonding cell, Figure 40 was created. The major causes of production loss and the financial value of each is plotted as a cumulative percentage of the total amount lost using the Pareto Principle. It is clear from Figure 40 that Operator motion (movement) and over time are the biggest contributors to production loss and needs to be investigated first. The figure is very close to the 80-20 rule, which would state that 20% of production losses are responsible for 80% of the total rand amount lost in the bonding cell.

Figure 40 Pareto diagram of production loss



The spaghetti diagram in Figure 41 shows the operator motion (movement) for the dry fitting process. It is clear that a lot of unnecessary actions take place in the process. A total distance of 80 meters where unnecessary walked by the operator in a process that takes 1.47 hours. (Please refer to Section 12.3.3 for the process time calculations of the bonding cell) The distance was calculated by measuring each individual movement of the operator in the cell and adding all the times together.

Figure 41 Operator motion for dry fitting process



To address the Operator movement problem, standard operating procedures (SOP) were developed and made visible to the employees. With standards in place, continuous flow could be developed and sustained. These standards will also help reduce the amount production loss. Once standards are developed employees will exactly know what is expected from them. They could even try to improve their performance by eliminating the non-value adding activities. With no standards set in place, there is no basis to measure against or improve on. SOP's can also be used as a training tool for new employees to explain certain processes and procedures.

The following information is included in a SOP:

- Cell layout
- Route mapping
- Internal suppliers to the cell
- Internal customers to the cell
- Name of the cell leader
- Name of the operator
- Workstation name (Cell name)
- Process name

An example for the standard operating procedures for the bonding and décor cell can be viewed in Appendix G. These SOP's were created for each task that is performed in the bonding cell and décor cell.

12.3.5. Critical Analysis Technique (5W1H)

In the bonding and décor cell, the partially completed galley is placed on a trolley to help move it around. For the curing process, the galley are simply pushed out of the way and left to dry for eight hours after which work will continue on the galley. These galleys are in the way of normal cell operations and there are no assigned spaces for curing in the cell. The current layout of the cell can be seen in Figure 42.

The curing time can be improved. It is difficult for the workers to move and work around these galleys. Workers also lose track of when the curing process started and most of the time the galley is left for a longer period than the prescribed time. This is valuable time lost in the assembly process and needs to be improved.

The Critical Analysis Technique is an important tool that develops the complete facts of a situation, it will be used to identify and evaluate different curing options which will be discussed in Section 12.3.8. The completed Critical Analysis template can be viewed in Table 22.

An alternative layout for the bonding and décor cell can be seen in Figure 43. For this alternative layout, there are predetermined curing booths for the galleys. The dry fitting tables where moved closer to the inspection area to reduce the distance travelled between these two areas. Dry fitting is followed by the bonding tables from where the galley will be moved into the curing booths. After the curing process the galley together with the trolley, will be moved to the assembly trolley parking space. Here the different attachments will be fitted onto the galley from where it will move out of the cell.
The advantages of the new layout:

- Increases communication (minimizes the distance between people)
- Easier to balance the workload between people because they can flex between jobs, help each other
- Easier to perform multiple operations

Together with this improvement heating plates can be attached to the sides and roof of the curing booth to reduce the curing time. An example of the design can be viewed in the Appendix I. This however will require a lot of collaboration with management to establish whether this will be feasible and beneficial to both parties.

In conjunction with this improvement, Appendix I illustrates a clock that will aid in the time keeping of the curing process. The alarm clock has large bright numbers and also has a built in alarm function that will alert the operator when the curing time is over. This improvement will only cost R450. Currently no time keeping measure is used to track the progression of the curing process.

Table 22 Critical Analysis Technique

CRITICAL ANALYSIS TECHNIQUE			
Method : Curing of bonded galley in bonding and décor cell			
PRESENT METHOD		**ALTERNATIVES**	**SELECTED ALTERNATIVE**
Purpose – What is achieved?	**Is it necessary? [yes/no] If yes - why?**	**What else could be done?**	**What?**
By leaving the bonded galley for eight hours to dry, the galley is ready to be handled again	Yes - The galley must first dry after bonding	Shortening the drying time	Shortening the drying time of the galley
Means - How is it done?	**Why that way?**	**How else could it be done?**	**How?**
The worker leaves the bonded galley unattended for eight hours to dry	No alternative methods	1. Controlling the air in the workplace 2. Curing oven 3. Heating panels 4. Dryers	Heating panels
Place – Where is it done?	**Why there?**	**Where else could it be done?**	**Where?**
Anywhere in the bonding and décor cell. The bonded galley is pushed out of the way and left to dry	Layout constraint, no dedicated area	The curing area can be situated in the bonding and décor cell	Dedicated curing area
Sequence – When is it done?	**Why then?**	**When else could it be done?**	**When?**
Done after inserts, panels, any attachments or subassemblies are bonded	Requirements of the process	Never (Not at another time)	While glue of galley is drying
Person – Who does it?	**Why that person?**	**Who else could do it?**	**Who?**
No one specific responsible, just left to dry			No one directly responsible

Figure 42 Current Layout of bonding and décor cell

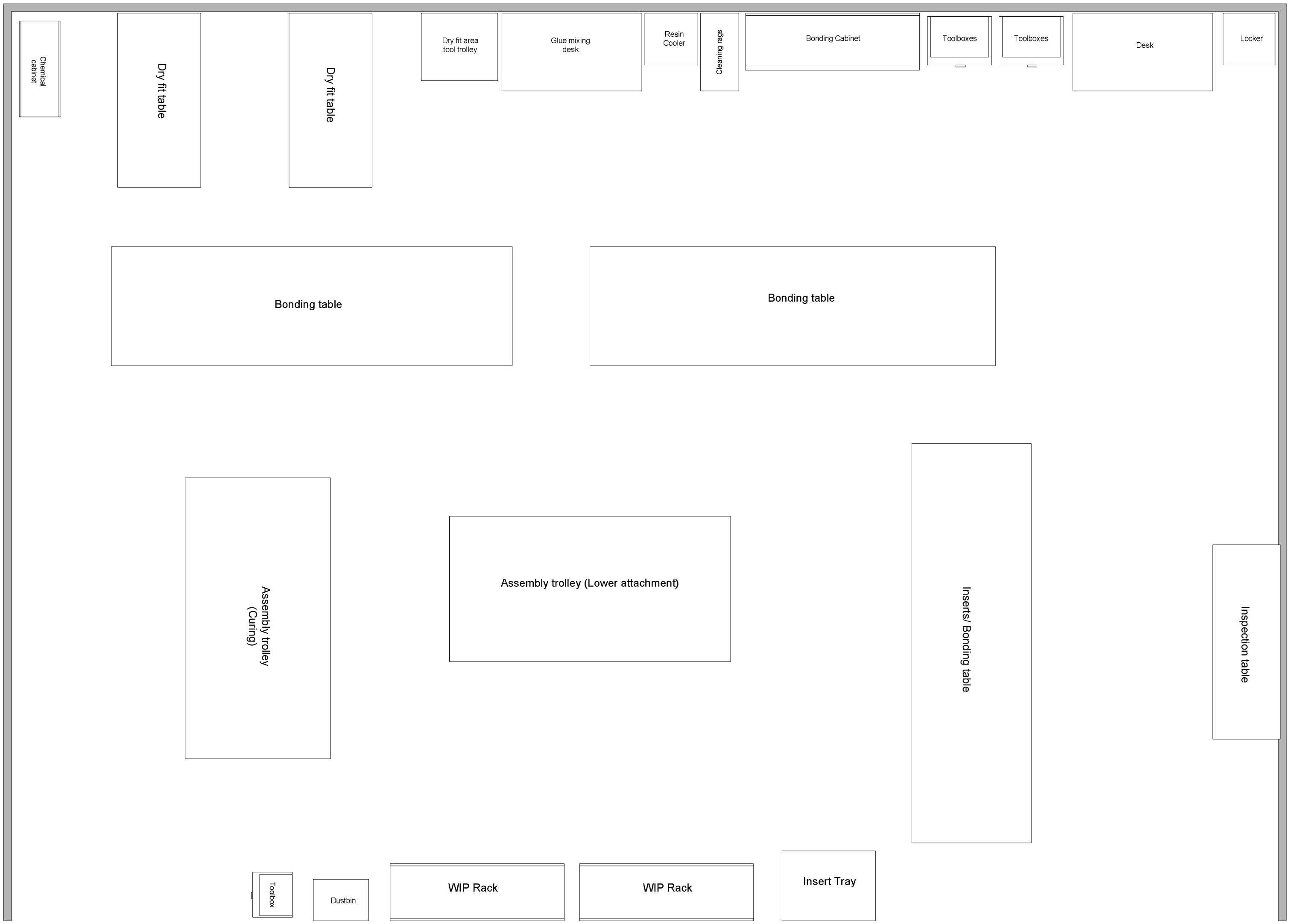
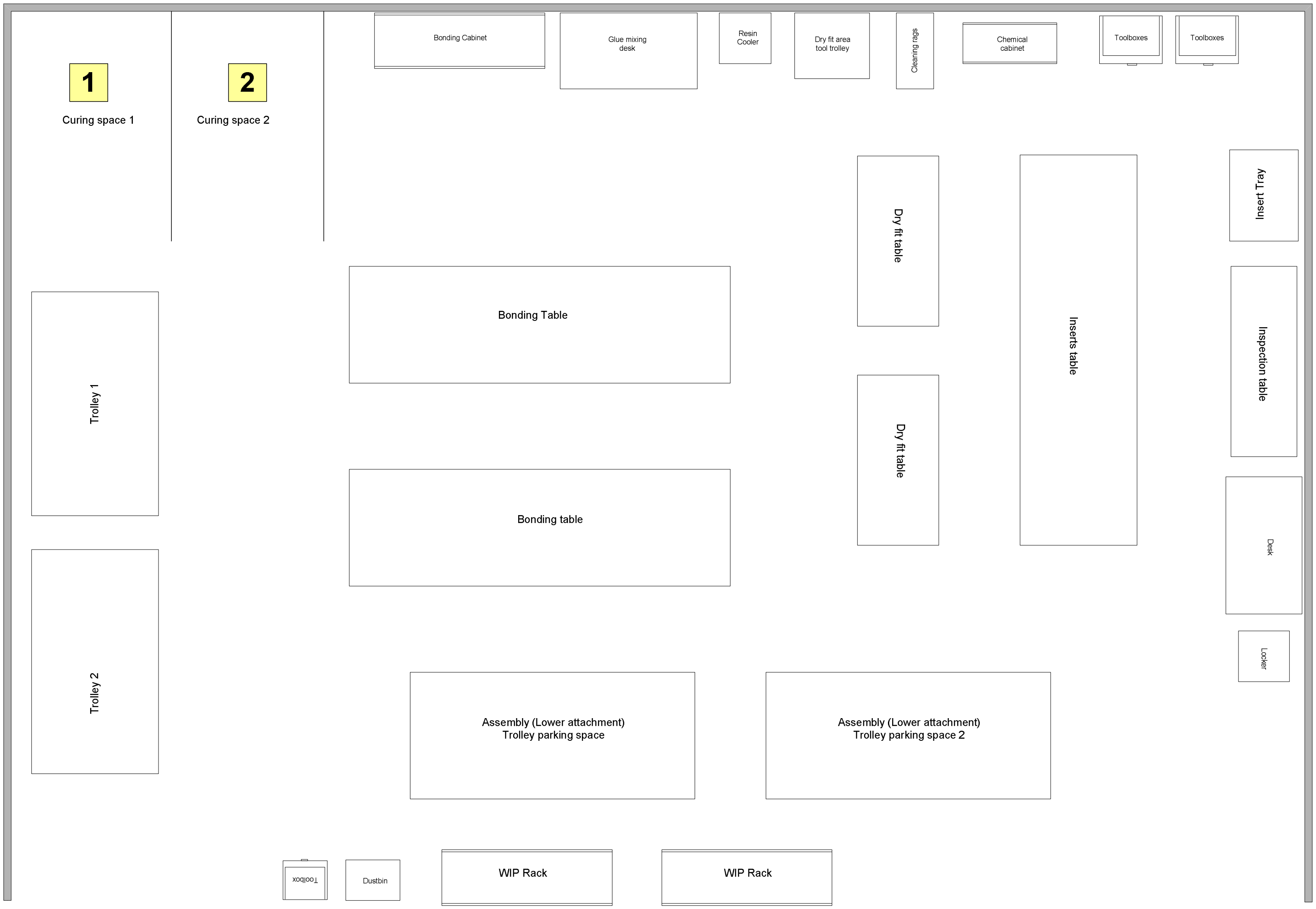


Figure 43 New proposed layout for bonding and décor cell



12.3.6 Flow Diagram

As mentioned in the project aim, continuous flow needs to be created. The flow diagram is a pictorial representation of the material flow in the bonding and décor cell. To create continuous flow in the bonding and décor cell, it is necessary to analyse the current material flow. Figure 44 summarizes the current flow in the bonding and décor cell. The material flow from process to process is represented by the arrows. It is clear that there is currently no continuous flow in the cell.

Figure 45 represents the new proposed flow in the cell. The new layout that was created in Section 12.3.5 will be used for the proposed flow analysis. The flow pattern in the proposed layout is a lot simpler and more linear than the current flow pattern. By implementing the new layout, the flow pattern in the cell will be improved and continuous flow will be created in the bonding and décor cell. The flow diagram facilitates developing the ideal layout.

Figure 44 Current Flow analyses

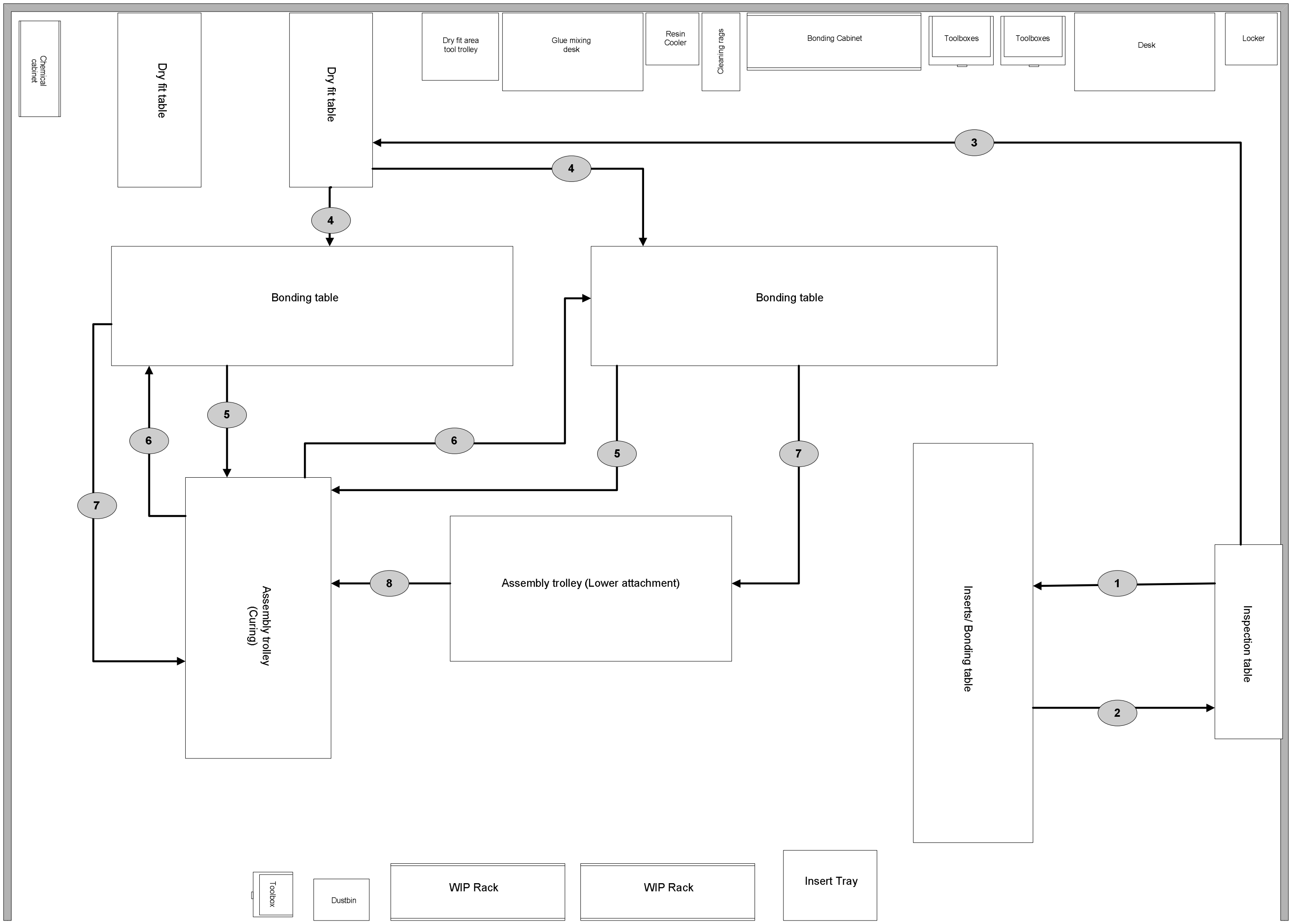
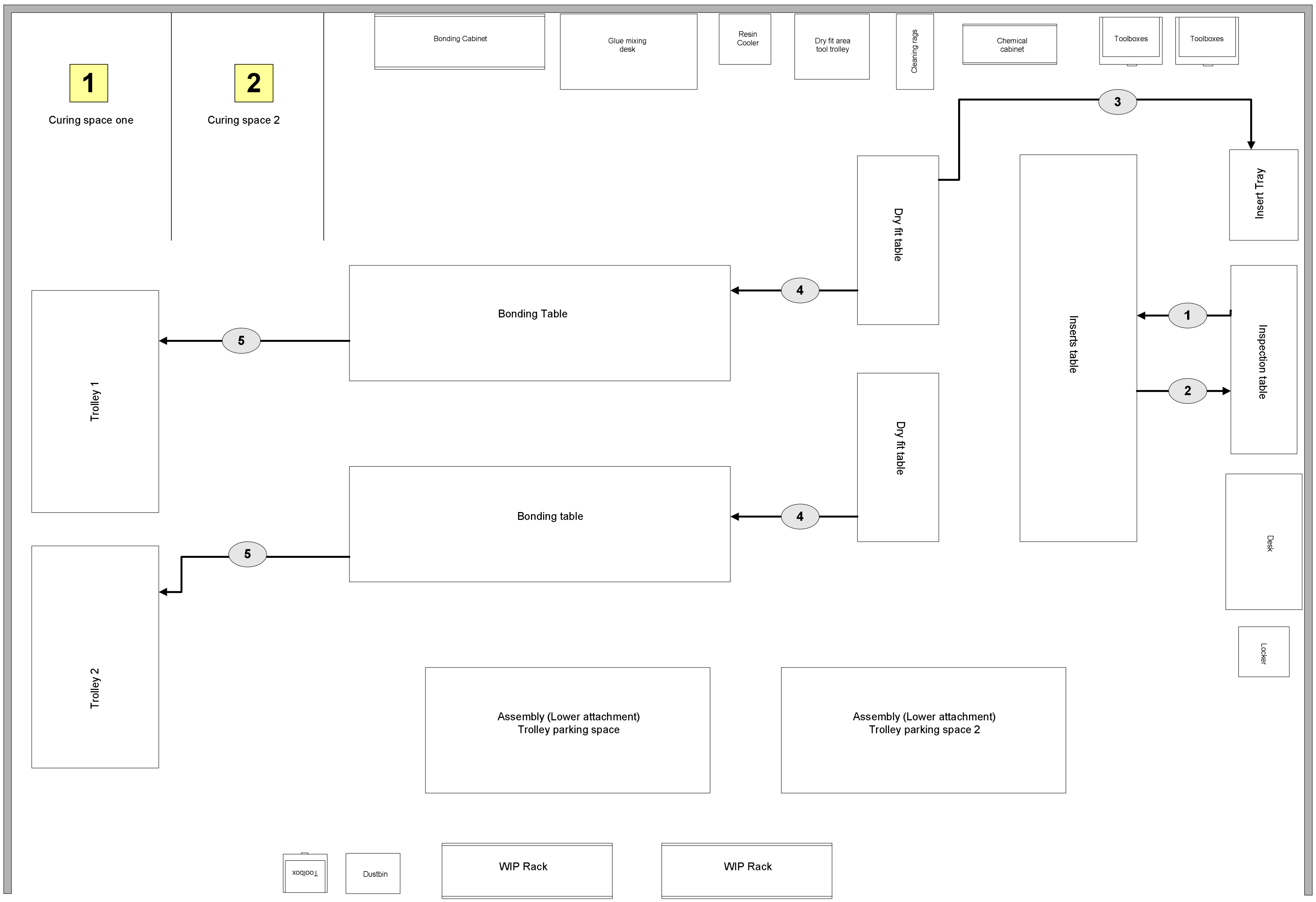


Figure 45 Proposed Flow Analyses



12.3.7 Simulation model

A simulation model was built using Rockwell's Arena 7.01. This was created to resemble the processes in the bonding and décor cell. The primary objective of the simulation model was to provide a dynamic environment to verify outcomes to different changes in the cell and be able to visually see the effect of the change. A few assumptions were made in order to compensate for uncertainties that had not been built into the model. These assumptions are the same as those defined for the current and future state simulation models in Section 11.4.

12.3.7.1 Pieces of the simulation model

The simulation model for the bonding and décor cell was built using the basic building blocks in Arena. The main objective was to resemble the operations of the cell in a dynamic form. The various parts that the simulation model will consist of:

- *Entities*

  Entities are the dynamic objects in the simulation. They usually are created, move around for a while, and then are disposed as they leave. The entities are represented by raw material that moves along in the assembly line and are transformed into the final product.

- *Resources*

  Resources represent all the different people working in the assembly. Specific names and processing values are assigned to each resource.

- *Processes*

  Processes require resources to be able to function. Raw material is transformed to the final product by the different processes.

- *Queues*

  The purpose of a queue is to supply a waiting place for the entity when the resource that it needs to seize is tied up by another entity.

- *Attributes*

  An attribute is a common characteristic of all entities, but with a specific value that can differ from one entity to another. These attributes that are assigned to each entity set a certain path so that the products can be processed.

- *Sub models*

  Sub models allow the user to define more complex and hierarchical logic for processing within a specific Process module. The contents of a sub model exist in its own world space, referred to as the sub model view.

Table 23 summarizes the building blocks that were used to simulate the above mentioned pieces of the model.

Table 23 Building Blocks of the simulation model

Building Block	Description
Create	➢ Raw material arriving according to a schedule ➢ Weekly delivery from stores to the assembly line ➢ Daily order from production control to stores ➢ Monthly customer order placed for the galley ➢ Monthly orders being fulfilled and delivered to the customer
Assign	➢ Assigning "Tnow" in order to calculate time in system ➢ Assigning entity pictures
Station	➢ Points in model to which entities are transferred
Process	➢ Intended as the main processing method in the simulation ➢ Seize, delay and release the product
Route	➢ Transfer the entity to the destination station specified
Decide	➢ Allows for the decision-making processes in the system
Record	➢ Collect count type and interval statistics in the simulation model
Request	➢ Assigns a transporter unit to an entity and moves the unit to the entity's location
Transport	➢ Transfers entity to a destination station
Free	➢ Release the entity's most recently allocated transporter unit
Delay	➢ Delays an entity by a specified amount of time
Dispose	➢ Ending the model, when the order is delivered to the customer

12.3.7.2 The model

The simulated process for the bonding and décor cell starts off with the panels that are received from the NC Cutting cell. The panels are created according to the customer order schedule until December 2009. The order schedule can be viewed in Appendix D. The panels are then assigned a "Tnow" value (attribute) in order to initiate the time in system variable. An entity picture is also assigned to the panels. The panels then seize the inspection worker for processing. The times for the processes are calculated using the Excel model that was discussed in Section 12.3.3. For the sake of uniformity, the same galley design will be used here to calculate the standard times of the processes. The drawer processes are not included in the simulation model because the same processes are followed as for the galley but only the process times differ. This will not influence the decision making. The detailed simulation model can be viewed in Appendix H.

The inspection process was modeled as a sub-model process, because of the high level of detail of the processes in the bonding cell. There are three outcomes for the inspection process. If the panel passes the inspection criteria, it will proceed to the insert process. Twenty percent of all the panels must be reworked and this is modeled as a delay of five minutes. Only five percent of panels are scrapped by the inspector and will be disposed.

After the inspection process the panel enters another sub-model, called inserts. Panels that passed the inspection process will enter the inserts sub-model and inserts will be inserted and glued into precut holes in the panels. This will be followed by a curing delay of eight hours to wait for the inserts to dry. The insert are then cleaned and tape is applied over it to prevent any damage to the insert. The panel proceeds to another inspection process which also can have three possible outcomes with the same probability.

The dry fitting process follows the inserts process where the whole galley is fitted together using tape to make sure that all the panels adhere to customer specification. The sides of the panels are then potted and must be left to dry for eight hours. Potting is then squared off with a file and the panels are ready to be bonded. The bonding process involves a lot of detailed and precision work. The bonded galley is then left to dry for eight hours and then moved to the attachment sub-model.

The attachment sub-model contains all the process that is involved attaching the different parts to the galley. The model starts off with the cleaning and sealing of the sides of the galley followed by the attachment of squares and spreader plates. The spreader plates are then cleaned and sealed by the workers. The amount of attachments that are needed for each galley differs from galley to galley. The attachments are measured out and then bonded onto the galley. Again the galley must be left to dry for eight hours. Various plates are attached to the galley to assist in the subassembly bonding later.

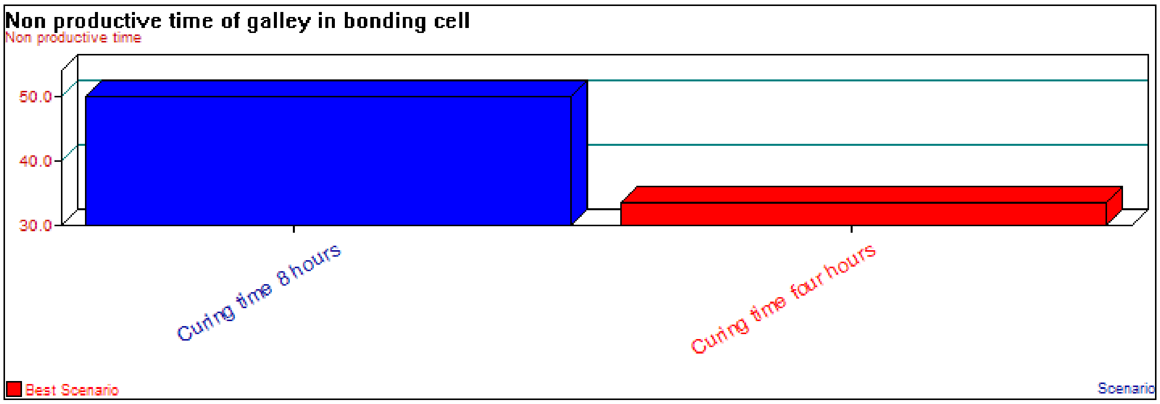
The different pieces of the galley are bonded together in the subassembly cell. After the bonding process there is again a curing time delay of eight hours. Various subassembly sides are then sealed and cleaned. The different subassemblies are bonded together to form the final galley. There will again be a delay of eight hours. The final finishing touches are done to the galley and then it will undergo the final inspection before it will move to the next cell. The time in system is recorded before disposal.

For the basic model, the panels were created according to the arrival schedule discussed above. The curing time will remain eight hours. The model was run for ten replications where each replication represented 30 days. The model for the alternative method is based on exactly the same principle and building blocks. The only difference is the delay times which simulate the curing time. The curing time can be reduced to four hours if a curing oven is used to speed up the curing process. The model was again run for ten replications, and the curing time where reduced to four hours.

12.3.8 Simulation Results

Rockwell's Process Analyzer was used to compare the non productive times of the two scenarios. Figure 46 displays the non productive time information.

Figure 46 Comparison of non- productive times



The curing time definitely has a big impact on the non-productive time in the bonding and décor cell. By reducing the curing time, the non productive time will reduce by 16.35 hours per month, which is equivalent to 2.33 working days.

12.3.9 Financial Implications of Improvements

From Table 24 it is clear that by making use of a curing oven the non-productive time can be reduced by 16.35 hours per month. The cost per hour of non-productive time in the bonding and décor cell is R456.00. The reduction in curing time will in return have a total of R89467.20 saving per year.

Table 24 Cost of non- productive time

Cost of non productive time in bonding and décor cell				
Bonding and décor wasted time	Period	Hours	Rate per hour	Total amount
Scenario one - Curing Time of 8 hours	Per month	49.1	R456.00	R22389.00
	Per year	589.2	R456.00	R268675.00
Scenario two - Curing Time of 4 hours	Per month	32.75	R456.00	R14935.00
	Per year	393	R456.00	R179208.00
Saving moving from scenario one to two	Per month	16.35	R456.00	**R7455.60**
	Per year	196.2	R456.00	**R89467.20**

13. Hypothesis Validation (STUDY)

Aerosud is struggling with the profitability of the galley assembly line. The combination of simulation modelling with their current Value Stream Mapping (VSM) approach will highlight more areas for improvement on the galley assembly line. Value stream mapping is static in nature because of it being a paper and pencil approach. By using modelling and simulation tools, in conjunction with value stream mapping, this limitation have been countered by providing a dynamic framework and toolkit, where current states can be simulated to identify the dynamic bottlenecks. A future state can be evolved based on practical simulations with improved processes and performance measures.

By using value stream mapping the proposed future state map would have been implemented and only after implementation, management would have realised that a major storage problem would have occurred at the systems cell. Simulation aided value stream mapping (saVSM) showed that this proposed future state map is definitely not realistic and provided the opportunity to test different scenarios to improve on the future state. The approach managed to reduce the queue of the systems cell to six galleys. Value stream mapping alone could not provide this testing opportunity. Aerosud can definitely be more effective if they combine simulation modelling with their current value stream mapping approach.

14. Conclusion (ACT)

Aerosud is currently struggling to make profit on the galley assembly line. The assembly line currently produces galleys at a rate of 3.3 ship sets per month, where the total loss per month is R562 463. They are experiencing trouble with the productivity of the assembly line and this result in inconsistent lead times and increased costs. There is a huge variation in the time parts spend in the assembly line. Aerosud has limited records of the product flow of the galley assembly line which makes it difficult to inspect the line and make improvements.

The aim of this project was to improve productivity that in return will have a positive effect on profit and create continuous flow. To improve productivity all the factors tending to reduce productivity must be considered as well as the primary sources of waste in the process.

The project was approached using the Deming (PDSA) cycle which consists of four stages: plan-do-study-act. Each of the stages has their specific objectives and outcomes. The logical sequence of the scientific method was applied within the Deming cycle stages.

Simulation Aided Value Stream mapping proved to be very practical for the analysis of the current state of the assembly line and also to create a desirable future state. It was also helpful in indicating the bottleneck in the assembly line. Two alternatives for the future state were evaluated and recommendations for specific applications were made.

The Bonding and Décor cell was identified as the problematic area that needed to be improved. The Bonding and Décor cell was analysed using the fishbone diagram. This identified causes to the problem which could be improved on. Simulation was used to evaluate different improvement opportunities of the flow in the binding and décor cell. Financial analyses were performed and the necessary recommendations were made.

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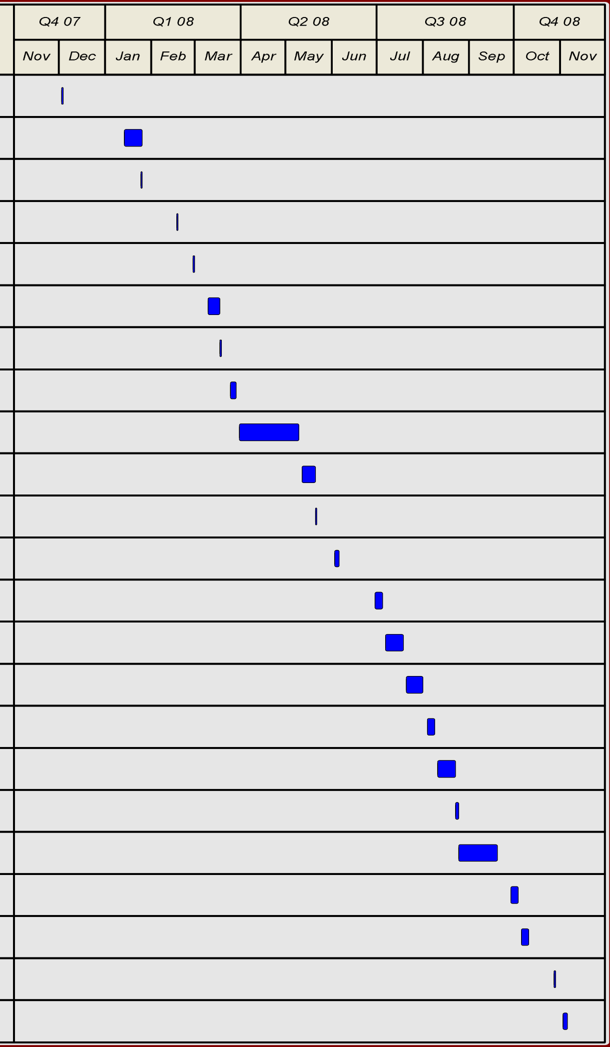
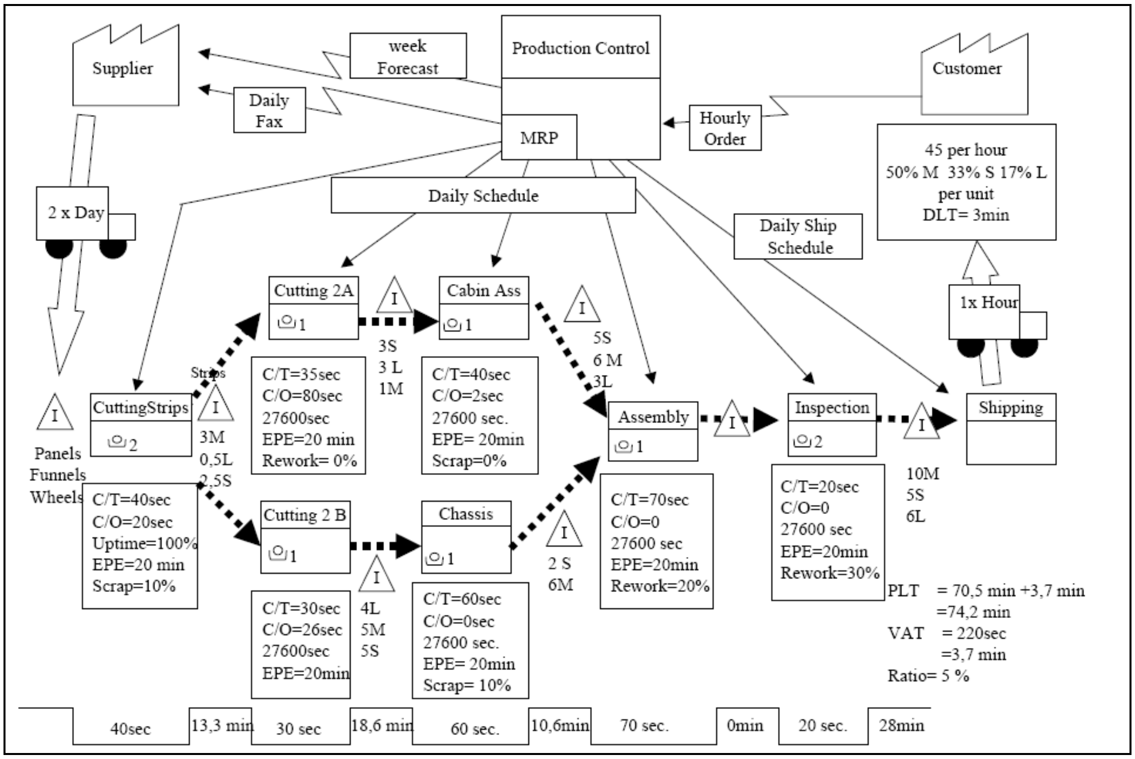
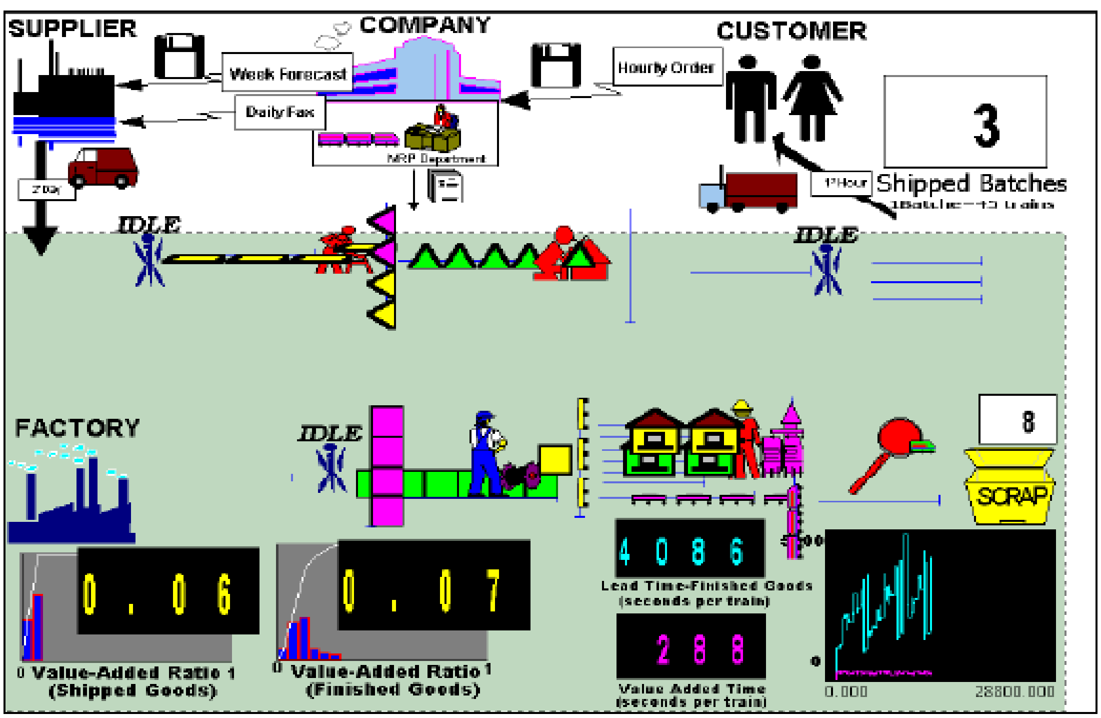
Appendix A – Project Approach Gantt Chart

ID	Task Name	Start	Finish	Duration
1	Topic selection with management	12/3/2007	12/3/2007	1d
2	Research ideas for project topic	1/14/2008	1/25/2008	12d
3	Topic Selection	1/25/2008	1/25/2008	1d
4	Project Topic Selection	2/18/2008	2/18/2008	1d
5	Meet project leader	2/29/2008	2/29/2008	1d
6	Research for project proposal	3/10/2008	3/17/2008	8d
7	Project Proposal Submission	3/18/2008	3/18/2008	1d
8	Value Stream Mapping Training	3/25/2008	3/28/2008	4d
9	Literature Research	3/31/2008	5/9/2008	40d
10	Interim Report preparation	5/12/2008	5/20/2008	9d
11	Submission of interim report	5/21/2008	5/21/2008	1d
12	BPJ 410 Presentation	6/3/2008	6/5/2008	3d
13	Simulation Software Training	6/30/2008	7/4/2008	5d
14	Phase 1: Research and current system definition	7/7/2008	7/18/2008	12d
15	Phase 2: Data processing and current state model generation	7/21/2008	7/31/2008	11d
16	Phase 3: Analysis and information gathering	8/4/2008	8/8/2008	5d
17	Phase 4: Idea generation and experimentation	8/11/2008	8/22/2008	12d
18	Phase 5: Feasibility Analysis	8/23/2008	8/24/2008	2d
19	Phase 6: Selection and development of future system	8/25/2008	9/19/2008	26d
20	Phase 7 ; Implementation of final solution	9/29/2008	10/3/2008	5d
21	Phase 8: Training tool development	10/6/2008	10/10/2008	5d
22	Final Project and poster submission	10/28/2008	10/28/2008	1d
23	Final Project Presentation	11/3/2008	11/5/2008	3d

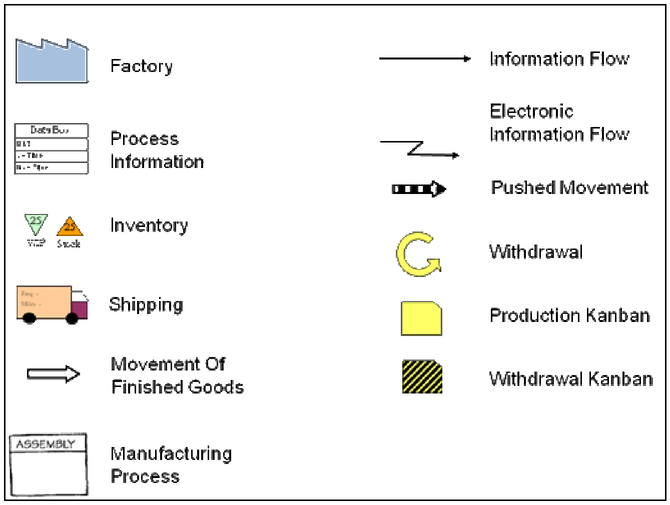


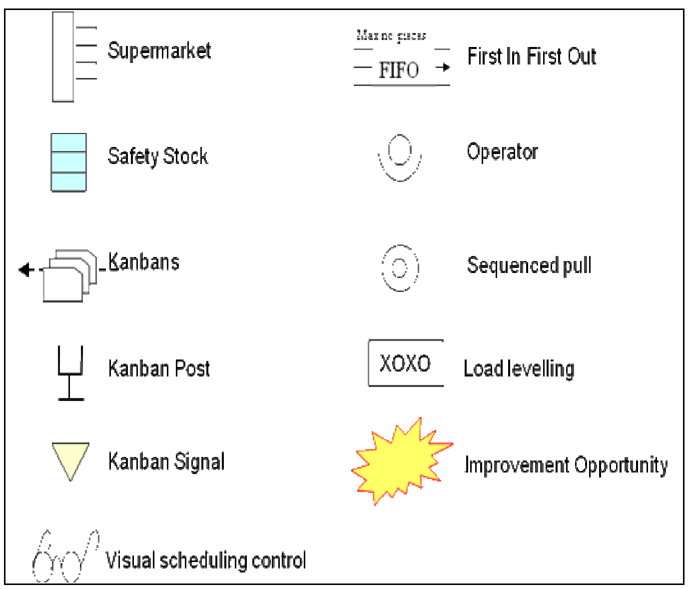
Appendix B – Simulation Aided Value Stream Mapping

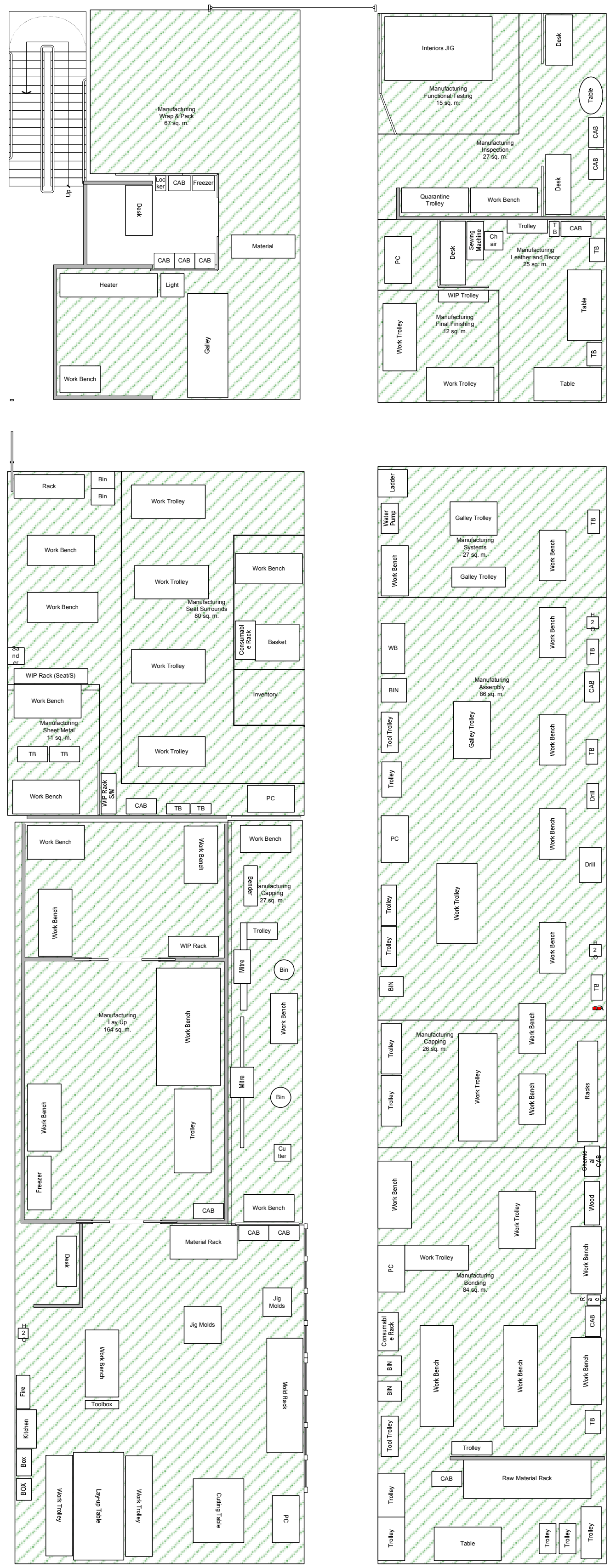




Appendix C – Value Stream Mapping Icons and Galley Assembly Line Layout






Manufacturing Wrap & Pack 67 sq. m.
Up
Locker
CAB
Freezer
Desk
CAB
CAB
CAB
Material
Heater
Light
Galley
Work Bench
Interiors JIG
Desk
Table
Manufacturing Functional Testing 15 sq. m.
Manufacturing Inspection 27 sq. m.
CAB
CAB
Desk
Quarantine Trolley
Work Bench
Trolley
CAB
PC
Desk
Sewing Machine
Chair
Manufacturing Leather and Decor 25 sq. m.
TB
WIP Trolley
Manufacturing Final Finishing 12 sq. m.
Table
Work Trolley
Work Trolley
TB
Table
Rack
Bin
Bin
Work Trolley
Work Bench
Work Bench
Work Trolley
Work Bench
Manufacturing Seat Surrounds 80 sq. m.
Consumable Rack
Basket
Work Trolley
Inventory
WIP Rack (Seat/S)
Work Bench
Manufacturing Sheet Metal 11 sq. m.
TB
TB
Work Trolley
Work Bench
WIP Rack S/M
CAB
TB
TB
PC
Work Bench
Work Bench
Work Bench
Work Bench
Bender
Manufacturing Capping 27 sq. m.
Trolley
WIP Rack
Mitre
Bin
Manufacturing Lay-Up 164 sq. m.
Work Bench
Work Bench
Mitre
Bin
Work Bench
Trolley
Freezer
Cutter
CAB
Work Bench
CAB
CAB
Material Rack
Desk
Jig Molds
Jig Molds
Work Bench
Toolbox
Mold Rack
Fire
Kitchen
Box
BOX
Work Trolley
Layup Table
Work Trolley
Cutting Table
PC
Ladder
Water Pump
Galley Trolley
Manufacturing Systems 27 sq. m.
TB
Work Bench
Work Bench
Galley Trolley
WB
Work Bench
TB
BIN
Manufacturing Assembly 86 sq. m.
CAB
Tool Trolley
Galley Trolley
Work Bench
TB
Trolley
Drill
PC
Work Bench
Drill
Trolley
Work Trolley
Trolley
Work Bench
BIN
TB
Trolley
Manufacturing Capping 26 sq. m.
Work Bench
Trolley
Work Trolley
Work Bench
Racks
Work Bench
Chemical CAB
Wood
Work Trolley
Work Bench
PC
Work Trolley
Manufacturing Bonding 84 sq. m.
CAB
Consumable Rack
BIN
BIN
Work Bench
Work Bench
Work Bench
Tool Trolley
TB
Trolley
CAB
Raw Material Rack
Trolley
Trolley
Table
Trolley
Trolley
Trolley

Appendix D – Order Schedule

Galley deliveries until December 2009			
PRODUCT	**No. of Units**	**MAN HOURS**	**G1 equivalent**
INDIGO # 22	2	2100	3
INDIGO # 23	2	2100	3
INDIGO # 24	2	2100	3
INDIGO # 25	2	2100	3
INDIGO # 26	2	2100	3
INDIGO # 27	2	2100	3
INDIGO # 28	2	2100	3
INDIGO # 29	2	2100	3
WIZZ AIR # 01	2	2100	3
WIZZ AIR # 02	2	2100	3
WIZZ AIR # 03	2	2100	3
WIZZ AIR # 04	2	2100	3
WIZZ AIR # 05	2	2100	3
WIZZ AIR # 06	2	2100	3
WIZZ AIR # 07	2	2100	3
WIZZ AIR # 08	2	2100	3
LHT A318 # 6	2	2200	2.5
LHT A318 # 7	2	2200	2.5
LHT A318 # 9	2	2200	2.5
LHT A318 # 10	2	2200	2.5
LHT A318 # 11	2	2200	2.5
LHT A318 # 12	2	2200	2.5
LHT A318 # 13	2	2200	2.5
LHT A318 # 14	2	2200	2.5
DLH A380 STOWAGES #01	4		2.5
DLH A380 STOWAGES #02	4		2.5
DLH A380 STOWAGES #03	4		2.5
DLH A380 STOWAGES #04	4		2.5
DLH A380 STOWAGES #05	4		2.5
Jet B757 G1, G2 G3	3	4000	4
A400M Galley # 01	1	1800	0.8
A400M Galley # 02	1		0.8
A400M Galley # 03	1		0.8
A400M Galley # 04	1		0.8
A400M Stowage #4	1	1200	0.4
A400M Stowage #5	1	1200	0.4
A400M FTI LININGS MSN1	1		0.4
A400M FTI LININGS MSN2	1		0.4
A400M FTI LININGS MSN3	1		0.4
A400M FTI LININGS MSN4	1		0.4
Jet BBJ2 Complex			5
LHT A319 G1&G5			3.5
AMAC G1 & G5			3.5
Total		**80,700**	**102**

Appendix E – Bonding and Décor Cell Processes

Bonding and decor cell processes
1. Inspection 1 of plates
2. Inserts
2.1 Putting in inserts and taping it
2.2 Glueing insert and cleaning insert
3. Curing for 8 hours
4. Taking off tape and cleaning insert
5. Tape over insert
6. Inspection takes place (visually inspected)
7. Dryfitting preparation
8. Dryfitting
8.1 Panel fit checked
8.2 Filing done to fit panel if not perfect
9. Potting
9.1 Preparation for potting
9.2 Potting applied to side panels
10. Curing for 8 hours
11. Square off potting with file/trowel - squaring it
12. Bonding
12.1 Bonding preparation (take off tape and file)
12.2 Mix glue (araldite)
12.3 Apply glue to sides of panels and slots
12.4 Position panels and let bonding take place
12.5 Clean with MEK (clean off glue)
12.6 File (Finishing touches)
12.7 Scraping of glue on sides
12.8 Squaring
12.9 Apply weights to galley and taping
13. Curing for 8 hours
14. Cleaning and sealing of sides
14.1 Apply sealer (glue)
14.2 Scrape extra off with file
14.3 Clean with MEK on cloth
15. Attaching squares and spreader plates
15.1 Preparation of spreader plate before bonding
15.2 Preparing spreader position in galley
15.3 Bonding spreader plate
15.4 Clean spreader after bonding with MEK
15.5 Preparing clamp and clamping spreader (curing for 8 hours)

Bonding and decor cell processes
16. Spreader plates - sealing and cleaning
16.1 Apply sealer (glue) on the sides with a stick
16.2 Clean with MEK on cloth (3 sides)
17. Measure out all attachments
18. Bond attachments
Steps differ from attachment to attachment
Attachments include: Cup attachments, Insert plates, Insert blocks, Light Inserts, Latches for top racks etc.
19. Curing for 8 hours
20. Attach joint plates to help with bonding process, will remove after bonding again
21. Sub-assemblies bonded together
22. Curing for 8 hours
23. Cleaning and sealing of sides
24. All sub-assemblies bonded together
25. Final finishing of galley
26. Curing for 8 hours
27. Final Inspection of the galley before moving out of the cell

Drawers of galley
1. Inspection of panels
2. Inserts in panels
3. Inspection takes place (visually)
4. Bonding of panels
5. Drying glue of drawer with heater
6. Scraping of excess glue of drawer
7. Seal sides of drawer
8. Clean after sealing
9. Preparation before potting
10. Potting
11. Put upside down (to square potting out)
12. Put weight on it
13. Clean of sides
14. Final finishing (file potting off)

Appendix F – Excel Model

Drawers of galley			
Step 1:	Inspection of panels		
How many panels?	30	Time	9000
Step 2: Inserts			
How many inserts in design?	36	Time	882
Step 3: Inspection of panels			
How many panels?	30	Time	9000
Step 4: Bonding of panels			
How many cups of glue?	3	Time	1357.2
How many sides to bond?	36	Time	1524.96
Step 5: Drying glue of drawer with heater			
How many drawers?	4	Time	2277.6
Step 6: Seal sides of drawers			
What length to seal? (in cm)	3	Time	1.3998
Step 7: Cleaning after sealing			
How many drawers?	5	Time	175
Step 8: Preparation before potting			
How many	5	Time	248.9

drawers?			
Step 9: Potting			
What length to apply potting to? (in m)	3.6	Time	671.76
Step 10: Square of potting			
How many drawers?	5	Time	600
Step 11: Final finishing			
How may drawers?	5	Time	432

Total time for drawers

Total Step 1 to Step 11 (in seconds)		26170.82
Conversion to minutes		436.1803
Conversion to hours		7.269672
Adding curing time (1*8 hours)		15.26967
Total time of drawers in bonding & décor cell (in hours)	**15.26967**	

Total time of galley in bonding & décor cell with time of drawers included (in hours)	**49.923683**

Appendix G – Standard Operating Procedure

STANDARD OPERATING PROCEDURE

Stores → NC Cutting → **Bonding** → Decor → Capping/Doors

Bonding of galley

CELL NAME: Bonding
OPERATOR NAME: G.Mosala, P. Ramatapa, S. Skosana
CELL LEADER: Johann Odendaal

AEROSUD

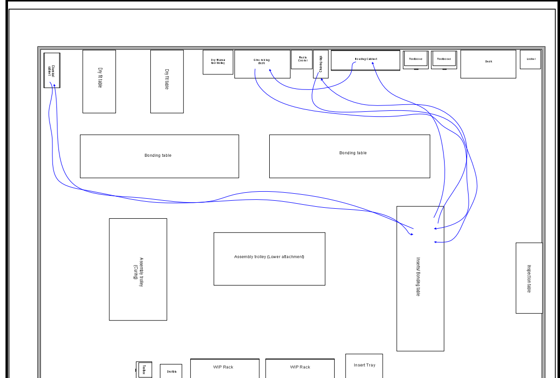
PROCESS INFORMATION*

DESCRIPTION	TOOLS REQ'D	VA / NVA / W	TIME
1 Bonding preparation (take tape of panels + file)	File	NVA	30 min
2 Mix glue (araldite)	Gloves, cup, mixer, scale	NVA	7.54 min
3 Apply glue to sides of panels (large)	Gloves and file	VA	1.65 min
4 Apply glue to sides of panels (intermediate)	Gloves and file	VA	1.46 min
5 Apply glue to sides of panels (small)	Gloves and file	VA	42.36s
6 Apply glue to slots in middle of panel	Gloves and file	VA	1.26 min
7 Position panels and let panels bond	Gloves	VA	18s
8 Clean with MEK (clean of excess glue)	Masks, gloves, MEK, cloth	NVA	7.03s per side
9 File (finishing touches)	File, gloves	NVA	1.23min per side
10 Scraping off glue on sides	File, gloves	NVA	
11 Squaring	Square	VA	4.25 min
12 Apply weights to galley and taping	Tape, weights	NVA	
13			
14			
15			
16			
17 *The time will differ from galley to galley, depending on the design			
18 *The total given is an estimated time for bonding a whole galley = 3.40 hours			
19			
20			
		TOTAL	3.40 hours
		TAKT TIME**	

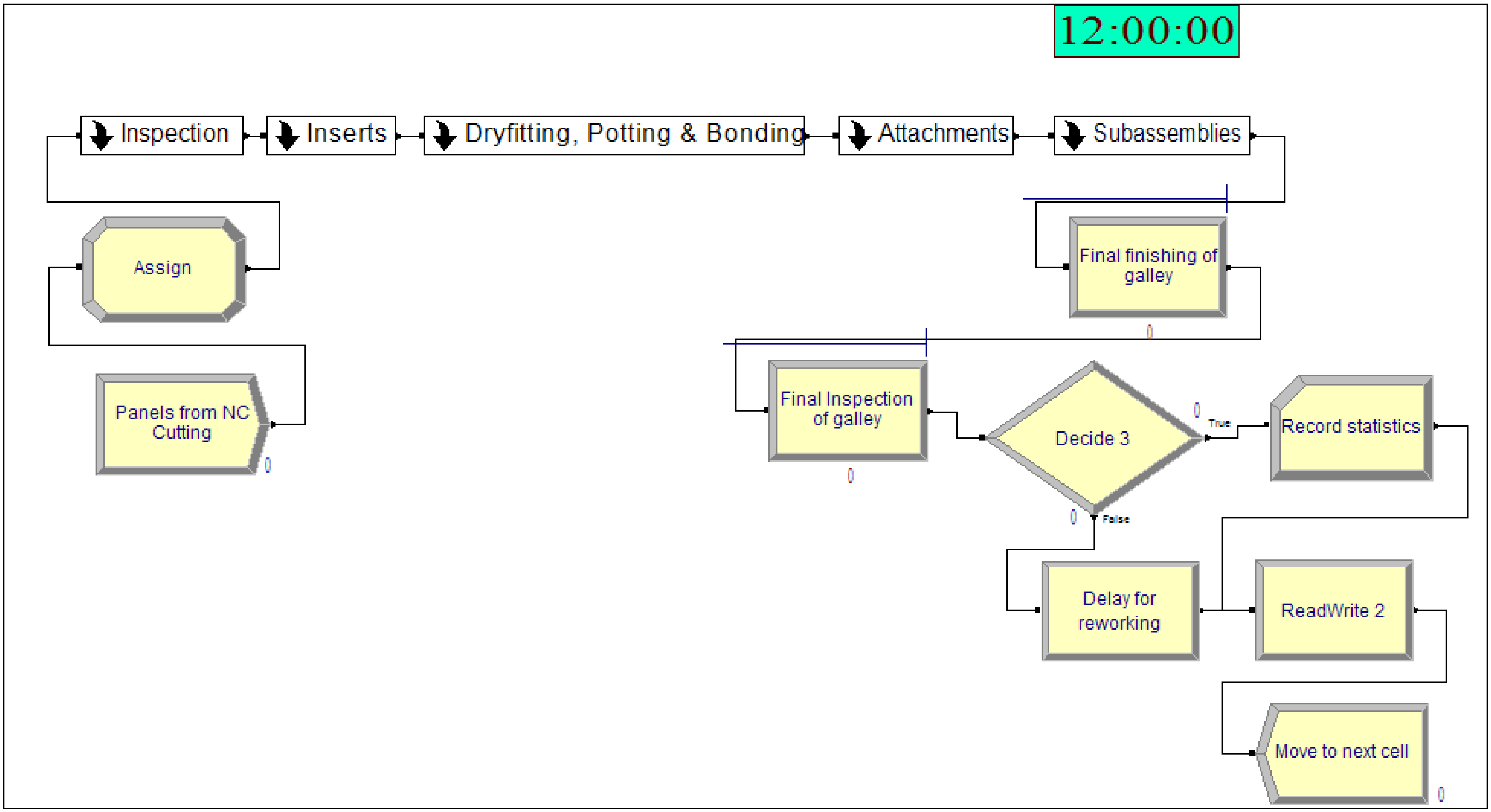
* The process information needs to run from the start of a PPS until the start of the next PPS. Use the average batch size for time calculation.

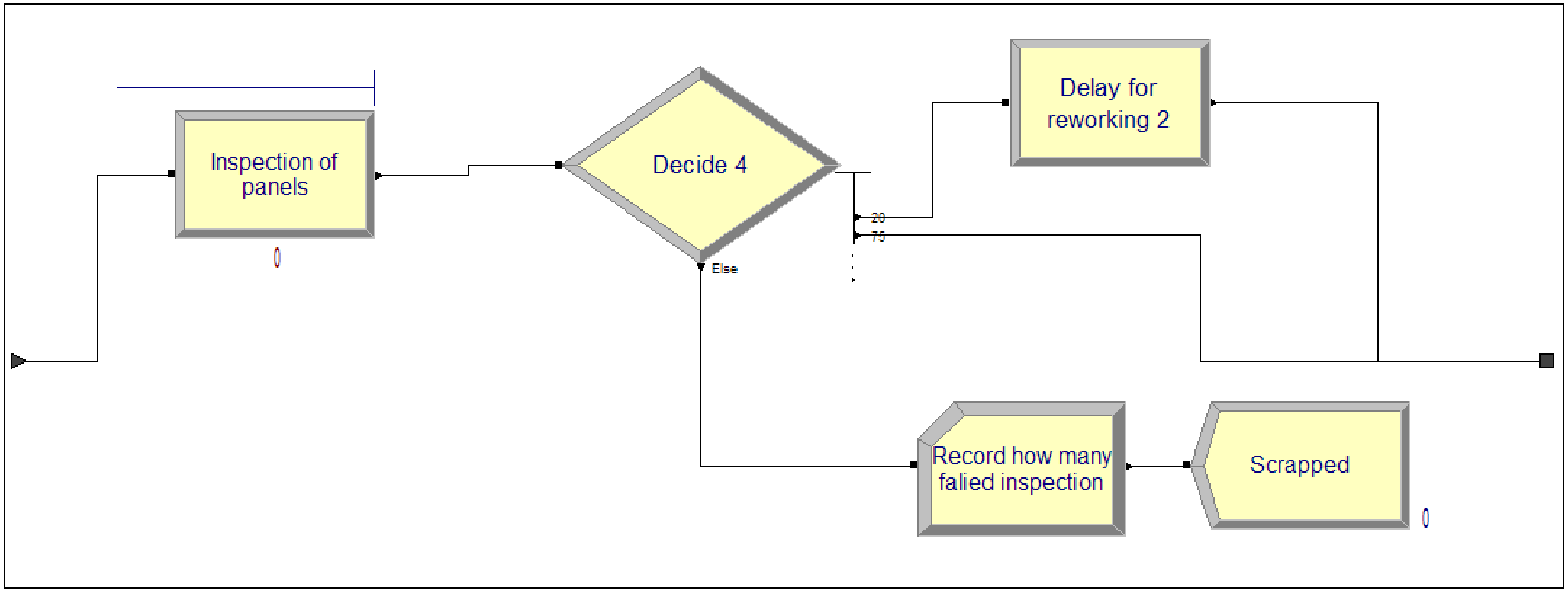
** Takt time is the total time allowed to manufacture the product. It is calculated by dividing the available time by the total customer demand.

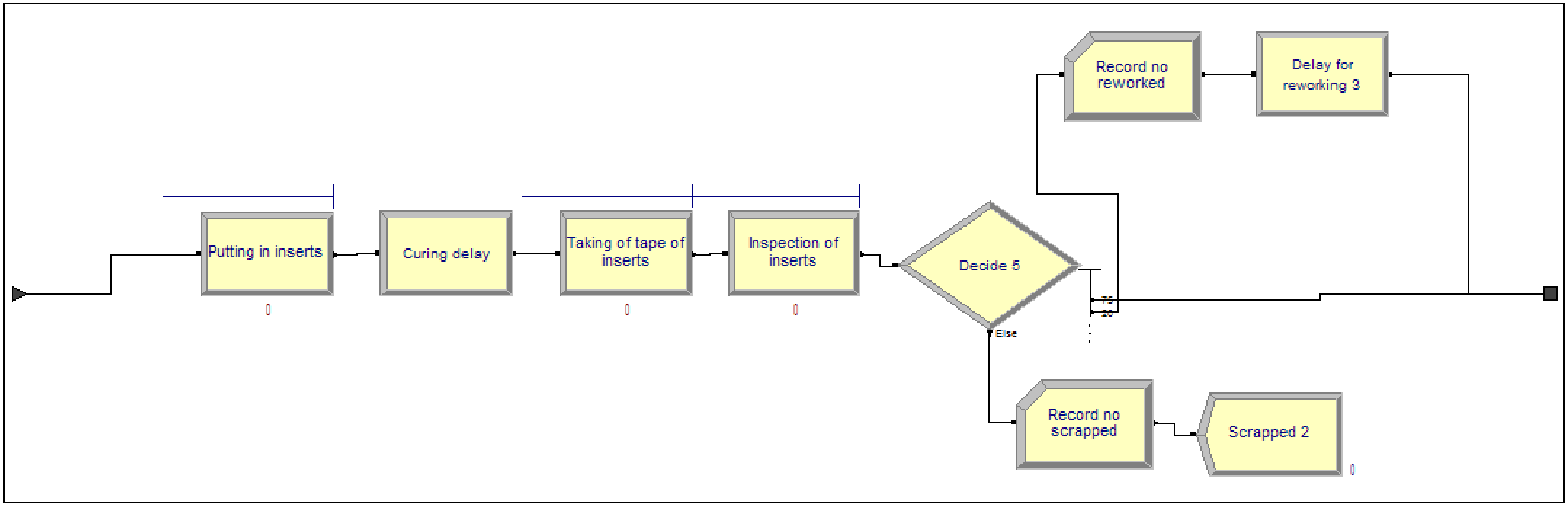
SPAGHETTI DIAGRAM & LAYOUT



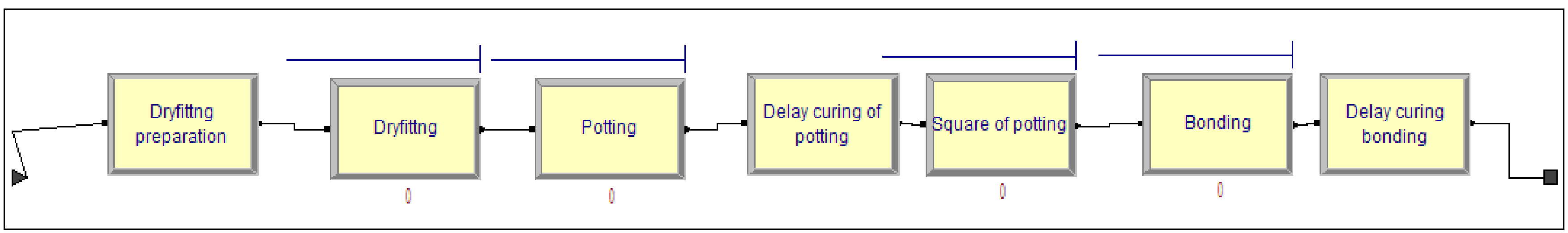
Appendix H – Bonding and Décor cell simulation model



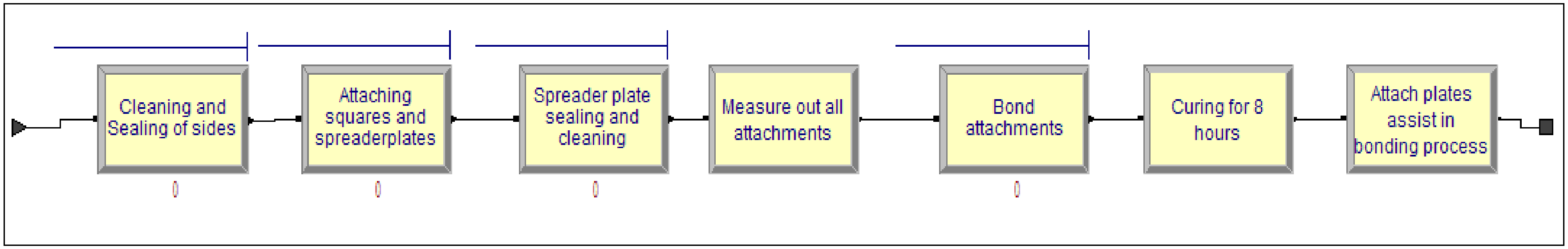

Inspection of panels
Decide 4
Delay for reworking 2
Else
Record how many falied inspection
Scrapped

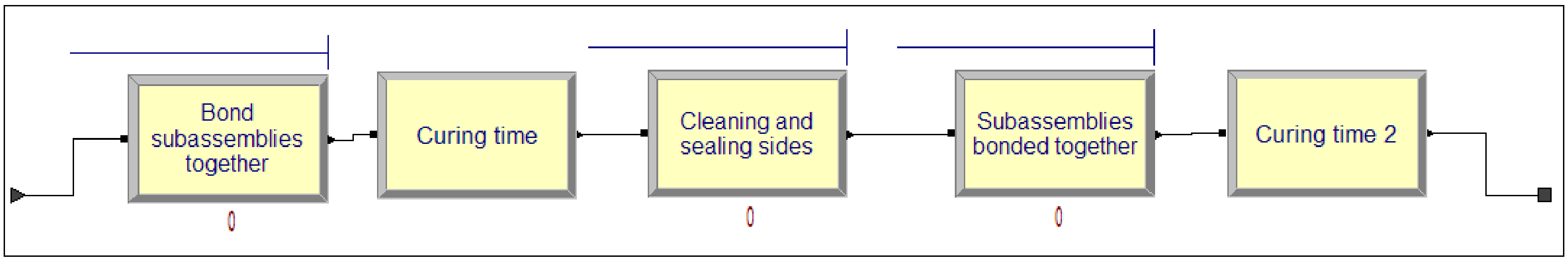


Record no reworked
Delay for reworking 3
Putting in inserts
Curing delay
Taking of tape of inserts
Inspection of inserts
Decide 5
Else
Record no scrapped
Scrapped 2



Dryfittng preparation
Dryfittng
Potting
Delay curing of potting
Square of potting
Bonding
Delay curing bonding


Cleaning and Sealing of sides
0
Attaching squares and spreaderplates
0
Spreader plate sealing and cleaning
0
Measure out all attachments
Bond attachments
0
Curing for 8 hours
Attach plates assist in bonding process


Bond subassemblies together
0
Curing time
Cleaning and sealing sides
0
Subassemblies bonded together
0
Curing time 2

Appendix I – Heating Plate Design and Clock