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Identifying Improvements to the Engine Assembly Line Simulation Philosophies within Ford Motor Company

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MRes THESIS

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Academic Year 2005-2006

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September 2006

This thesis is submitted in partial fulfilment of the requirements for the degree of Masters of Research

Abstract

Ford Motor Company (Ford) utilise unique simulation models to represent the behaviour of their diesel engine assembly lines. The simulation model is a computerised tool used to support modification decisions that affect the assembly processes and productivity of the lines. The stakeholders, who use the simulation outputs, lack complete confidence in them. The doubt appears to stem from a lack of documentation to prove that the model accurately represents the assembly line.

This research aims to increase confidence in existing simulation models of the engine assembly lines in Ford. To achieve this, the logic behaviour of the existing Lion Assembly Line (LAL) is analysed. It is found that the LAL can be decomposed into repeatable elements by identifying common attributes and inter-element boundaries. Representational logic diagrams are produced, then verified and validated from the perspectives of key stakeholder functions. The accurate logic diagrams are composed into an Assembly Line Specification (ALS) which is used to identify gaps and correlations between the actual LAL behaviour and the simulated logic. The findings are that the simulation accurately matches reality in the majority of cases. However, there are important differences identified that require consideration during model construction.

The research and development completed gave rise to the observation that model confidence could be increased to a greater extent by specifying not only the assembly line, but the whole simulation process. The content and framework identified of such a document allowed the critical analysis of the current simulation strategy within Ford to identify possible improvements to the current philosophies employed.

The completion of this research and production of an ALS has increased the confidence held in the simulation model, identified ways to accelerate the modelling process and aid Ford Motor Company to remain a world-class diesel engine manufacture.

Acknowledgements

I would like to firs thank Ford Motor Company for sponsoring this project particularly the industrial supervisor John Ladbrook, who has provided the focus for this research. Thanks also to the Productivity and Process teams, namely: John Hall, Roy Lilly and Demiji Alli. My thanks also extend to the Control System and Assembly line specialists, with whose helped made this research as thorough as it is.

My thanks are also given to Dr. Benny Tjahjono, my academic supervisor, whose supervision and ability to focus my efforts undoubtedly deserve credit.

I would also like to give my gratitude to Emma Waples and Ruth Murdoch for assisting me through the troublesome arrangements of hire cars and hotels, I am confident that without their help I may still be stuck somewhere in the heart of Essex.

Heartfelt thanks extend also to my family for helping me through the year offering guidance and a kick up the …when needed. The same go to my new found friends and colleagues from Cranfield who are always there to share the burden. They have been constant source of inspiration and helped me to forget stressful times over a good barbeque and bottle of wine.

One big thank you to anyone I have missed off from this, Thanks Mr Bigu P. Yosef.

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Acronyms and Glossary

AGV	Automated Guided Vehicle
ALS	Assembly Line Specification
Automation	Part transportation equipment
BCL	Batch Code Language
Boundary	A conceptual limit of an element
Breakdown	Failure of an element to complete cycle
Buffer	Part holding capacity of automation
CML	Continuous Moving Line
CT	Cycle Time
Cycle	An interval during which a recurring sequence of events occurs
Cycle Time (CT)	Time taken to complete a cycle
Derivative	A variation in the Part from the generic base
DES	Discrete Event Simulation
DTD	Document Type Definition
Element	Repeatable component of a system
FAST	Ford Assembly Simulation Tool
Flow	The movement of parts through the system
GDP	Gross Domestic Product
HTML	HyperText Markup Language
IDEF0	Integration DEFinition language 0
Interaction	The exchange of information or parts between elements
JPH	Jobs Per Hour
JSP	Jackson Structured Programming
KBMC	Knowledge-Based Model Construction
LAL	Lion Assembly Line
Logic	The sequence of events that take place
Metamodel	A model which describes a model
NIST	National Institute of Science and Technology
OEM	Original Equipment Manufacturer
Part	Component transported through system
Platen	Part holding device
PLC	Programmable Logic Controller
Pre-stop	Stop before an element
RFID	Radio Frequency IDentification
SCL	Simulation Control Language
SRS	Software Requirement Specifications
SSD	Simulation Specification Document
Stop	Stopping device in assembly line
Takt Time	The rate at which parts have to be produced to match the customer requirements
UML	Unified Modelling Language
V & V	Verification and Validation
WIP	Work In Process

1 Introduction

This chapter introduces the problem that gave origin to the research, defines the methodology followed to address this problem and describes the structure of the thesis.

1.1 Purpose of the Research

The research, investigation and development reported in this work comes from the identification of an issue with the creation of a document that can be used to prove the logic of a simulation model. A simulation model in the context of this research is a mathematical representation of a reality configured with a specially developed user interface. The logic in a simulation represents the behaviour of parts through the real system.

The issues raised originate from Ford Motor Company's Productivity Department. The root cause of this industrial problem identifies that the need to develop a document stems from a lack of confidence in the simulation model. The doubt in the model reduces the level of confidence in decisions made from the output data of the Assembly Line Simulation models. The assembly line analysed produces variations of 'V' configuration engines. It is referred to as the Lion Assembly Line. They are produced for Ford brand vehicles and for other original equipment manufacturers (OEMs).

Matters relating to simulation model documentation have been around since at least 1977 (Highland, 1977). The content requirements of simulation documentation, such as the real system logic, are well documented (Carson, 2005, Gass, 1984 and Nordgren, 1995). The approach to document development is neither standardised nor recommended, meaning the simulation experts within Ford have not developed the specification document format or content.

1.2 Overview of the Research Methodology

A potential solution allows the following aim to be achieved:

“Increase Confidence in Simulation Models of the Engine Assembly Lines within Ford”

The solution to the industrial problem targets the development of documentation to specify the real system in enough detail to identify gaps and close correlations in the underlying logic of the simulation. To complete an Assembly Line Specification and achieve the aim the following objectives have been established:

1. To analyse and represent the Ford Lion Assembly Line logic.

2. To verify and validate representations of the Lion Assembly Line logic.

3. To develop an Assembly Line Specification.

4. To critically analyse the use of the Assembly Line Specification to improve the simulation strategy within Ford.

1.3 Structure of the Thesis

Chapter 2: Industrial context

This chapter contains an introduction to the key issues and relates them to the specific problems faced by Ford Motor Company. The issues of Ford in the UK manufacturing context are discussed. Some background is given on the nature of the facility under study and also introduces the context of simulation.

Chapter 3: Literature Review

This chapter identifies literature related to solving the industrial problem. Firstly the simulation in this context is investigated. The concepts, issues and current developments of simulation documentation can be understood in this chapter.

Chapter 4: Research Methodology

The research aims, objectives and methodology are stated with the target deliverables from each stage in this chapter.

Chapter 5: Lion Assembly Line Logic Analysis

This chapter presents Stage 1 of the methodology. This chapter conveys the analysis of the Lion Assembly Line. The completion of this stage gives initial representations of the LAL logic to be validated.

Chapter 6: Logic Diagram Verification and Validation

This chapter presents the Verification and Validation (V & V) of the preliminary logic diagrams carried out from three differing perspectives. These perspectives are from the Control System, Simulation and Assembly Line.

Chapter 7: Assembly Line Specification Creation

The purpose of this Chapter is to convey the process taken to produce a specification of the Lion Assembly Line. The assembly line specification is analysed and possible solutions to the issues raised are presented.

Chapter 8: Assembly Line Specification Utilisation

The Assembly Line Specification (ALS) produced and the Simulation Specification Document proposed support the analytical process in this chapter. The ALS is used to identify disparity between the simulation model logic and the Lion Assembly Line logic in the first section. Potential improvements to the simulation strategy within Ford using a complete Simulation Specification Document (SSD) are critiqued.

Chapter 9: Discussion and conclusions

This final chapter presents the research findings from each stage, the key findings are also compared to the original research objectives. Short, medium and long term recommendations are also made to Ford as the result of the completion of the research. Contributions to knowledge, limitations and suggestions for further work conclude the research.

2 Industrial context

This chapter describes an introduction to the issues and focuses them to the specific problems faced by Ford. The chapter follows a path to the specific issues via the UK manufacturing context, assembly line background and through the concepts of simulation in Ford.

2.1 UK Manufacturing

Despite the ‘bad press’ that the UK manufacturing industry receives from the media the industry represents approximately one sixth of the UK’s Gross Domestic Product (GDP) and is responsible for over half of the UK’s exports (DTI, 2004).

The UK manufacturing climate is becoming increasingly pressured by consumers to continually reduce prices yet increase product performance. Pressure is also applied to individual companies by the government and industry to retain manufacturing within the UK. The UK manufacturing industries must therefore be able to globally compete on cost, quality and to retain their market share.

Global competition, particularly from the emerging economies, is well known to produce low cost products. Alarmingly, this competition from these emerging economies is becoming increasingly sophisticated with the ability to compete with the UK’s quality and technology level. To keep ahead the UK must lead the adoption of new technologies and techniques as well as focusing on education (Brown , 2006).

Manufacturing organisations globally and particularly in the UK, have experienced a reduction in demand caused by sharp down turn in the world’s economy in 2001. Investment and productivity increases coupled with reduction in job loss rates suggest that the industry is once again gathering momentum (DTI, 2004). Many organisations are adopting new and well proven manufacturing tools, techniques and philosophies to counteract the effect of high salaries. Unfortunately for the industry and the local population this often results in job losses. This situation is prominent around the location of Ford Motor Company in Essex to the East of London. This location in the southeast of the UK has one of the highest average salaries in Europe.

2.2 Ford Motor Company

Ford Motor Company (Ford) has a history dating back to the 16th June 1903 in Michigan, USA. From there the company produced automobiles for a mass, widely distributed market. The popularity of the automobiles produced grew rapidly in the UK from the very first consignments of Ford automobiles arriving late 1903. The rapid increase in UK automobile demand supported the opening of the first Ford factory on the outskirts of Manchester, England. Further demand increases meant that it was necessary to open another plant for which the Dagenham site in Essex was chosen. At the time the Dagenham site was the largest automobile manufacturing plant in the Europe. There are many Ford manufacturing facilities throughout the world, using standardised processes and techniques to manufacture and assemble components to build the following 8 brands:

- Aston Martin
- Ford
- Jaguar
- Land Rover
- Lincoln
- Mazda
- Mercury
- Mustang

The complete assembly of motor vehicles has recently ceased at Ford Dagenham. The concentration is now on the manufacture and assembly of engines. This is partly due to lower labour rates in other locations of automobile facilities. Engines assembly is retained in Essex mainly primarily because of the centre of excellence for diesel engines, employing specialist diesel engineers from the around the UK. The engines are distributed to numerous European countries to be installed into Ford vehicle brands. Ford automotive engines are also manufactured in places throughout Europe, for example in the UK there are other assembly lines in Bridgend, Wales. The assembly lines also have the ability to produce engines for third party customers such as PSA Peugeot Citroën. This research examines a Diesel Engine Assembly Line, known as the Lion Assembly Line (LAL). The engines assembled on this line have a 'V' configuration of Cylinder Block, Head and Pistons.

The competitive climate and external pressure on Ford, as a UK manufacturer, requires Ford be a world class plant producing world class products (Parker, 2006). This can be achieved by continually improving the performance of the products and the assembly lines. It is the performance of the assembly lines that this research focuses on. The LAL at Dagenham is a large complex system, consisting of many different operations, workers, control systems and components.

2.3 Assembly Lines

Assembly lines are manufacturing processes that add parts in a sequential order to achieve a single finished product. The Lion Assembly Line employs proven manufacturing techniques and philosophies. One such philosophy is Lean manufacturing. The LAL is a benchmarked example of such techniques and uses many manufacturing management 'tools' to achieve this status. A target of a Lean principle is to reduce batch sizes of manufacturing to 1 to allow the product mix to be flexed so as to closely match actual production with customer demand. Increasing the different types of products possible to manufacture on the same flexible line can then be done. The achievement of this can be witnessed on the LAL as the line is capable of producing the derivatives in Figure 2-1:

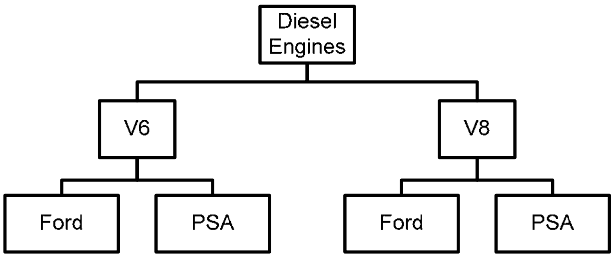


Figure 2-1: Outline Derivative Possibilities of Lion Assembly Line

The outline derivatives can be broken down further into engine orientation (when installed in a vehicle) derivatives.

Another philosophical goal of Lean is to eliminate all sources of waste from a process. A major waste in Lean terms is the waste of over production. This is wasted time, effort, resources and money used to produce parts that are not for immediate sale to customers. To prevent this waste in Ford, the line assembles according to a production plan based on accurate demand forecasting. The plan gives the target number of engines to produce per hour. This desired rate to meet the predicted demand sets the pace of the line to prevent engines overproduction. Each operation is designed to meet this pace. For example the LAL production plan at the time of this research is to produce 110,000 V6 engines (derivatives combined) this equates to a maximum operation cycle time of 100 seconds. This time can be referred to as the Takt Time or line drumbeat.

To maintain competitive advantages, changes are required to be made to the LAL to react to variations in demand and customer requirements. Employing Lean philosophies increases the flexibility and responsiveness of the line. However, continual improvements to the line are made cautiously. The continual changes pose problems when considering the complexity of the system, high volumes of production and direct costs required when making the engines. Making changes to the line can be expensive, especially if they are incorrect. Inappropriate variations to the line may cost time to correct it, lost production and indirect costs, all that have to be absorbed. For this reason various tools and techniques are available for a company to test out ideas to assess the results of such changes prior to implementation. Simulation is one such tool.

2.4 Simulation

A simulation is a mathematical representation of reality and, in context of the tools in Ford, has a user interface. The LAL is represented within the program in terms of data and logic. An example of data is the cycle time of an operation. The logic of the system is how the simulation depicts the processing and flow of a Part through the system. Simulation tools are powerful and, with experience, are moderately simple to use. Simulation tools are applied to many different industries and are almost limitless in their variations. For example, simulations can be used to model people entering a bank or to assess the possible benefits in mining a particular area of natural resource. The simulation package used at Ford is “Witness” (Lanner Group inc., 2004). Witness was written by The Lanner Group who have collaborated with Ford in developing a range of solutions for the simulation needs in Ford (Winnell and Ladbrook, 2003).

Complex systems, such as the LAL, consume a large amount of time and resource to model to high levels of detail. On the other hand, whilst constructing models using a low level of complexity may be suitable for many applications a simple model may not represent the intricate logic between the components of the LAL. In this case the model stakeholders may tend to disagree with the behaviour of the model and not trust the outputs. The trade-off between model detail and the required resources can be illustrated simply by the curve in Figure 2-2.

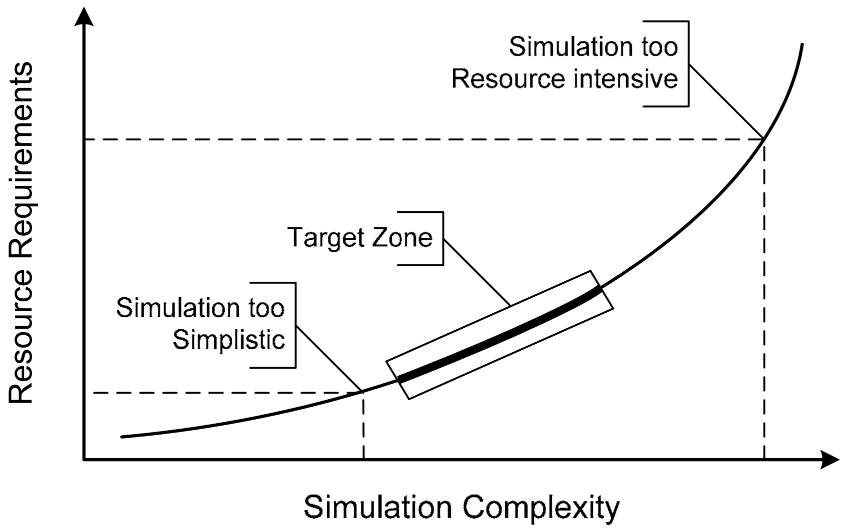


Figure 2-2: The Simulation Complexity Trade-off

The complexity level depends on stakeholder requirements. Simulation model stakeholders in the context of this research are Simulation Specialists, Simulation Novices, Productivity Engineers and Process Engineers. Verification ensures that a model matches reality to an appropriate level (Target Zone, Figure 2-2). Increased data requirements of complex models generally equate to extensive data collation and more people involved, thereby increasing the need for careful management of the process. All of these factors can add time and cost onto the model construction phase before the model is used for solution experimentation. An issue with the LAL is its physical size and inherent complexity making target zone difficult to define. To simplify the model building process Ford have developed standard tools to reduce model building complexity and ease repetitions on different manufacturing lines.

2.5 Ford Simulation Tools

Simulation tools used in Ford on the Lion Assembly Line are applied to all engine assembly lines throughout the UK. The tools assist production planning to meet customer demand by providing information to determine the Takt Time of assembly line operations. The simulations model how the installed components, such as men and machines, are planned to operate. Simulation is the responsibility of the Productivity Department at Ford and the Process engineers use them for some planning activities. Process Engineers use the simulation models for buffer size optimisation. Optimisation of the buffers is necessary to balance in-line stock holding or Work In Process (WIP) with operation starvation issues due to breakdown situations. Productivity Engineers use the simulation to plan where to place people to optimise personnel utilisation and line output.

The standard interface with Witness is user friendly where relatively low levels of model complexity are involved. However, the complexity of the assembly lines and level of accuracy required to predict the effect of small changes to the lines made the standard interface arduous to use. This level of complexity meant that it is difficult for non-simulation experts to use the model, so not releasing the simulations' potential. Increased use of simulation models within Ford UK has been accomplished by designing tools to make the simulation models easier to use. This tool is Excel Spreadsheets combined with a Visual Basic interface to a Witness model, known as Ford Assembly Simulation Tool (FAST) (Winnell and Ladbrook, 2003). The FAST tool is applied to all engine assembly lines in the UK and others in Europe and North America. FAST has increased the use of the models by improving the accessibility of the results. FAST is predominantly UK based and there are few simulation experts within Ford Motor Company worldwide meaning that other plants outsource the complex models. The models within Ford Motor Company UK can be applied as a worldwide standard. However, due to the complexity of the specific models, the simulation building functions are outsourced, introducing increased risk and cost to the specific plant.

The simulation models are run by various people within Ford using their local copies of the FAST program to modify input parameters to the Witness model in the background. The Witness software is run locally with access to a licence from a central server, enabling the distribution of the simulation through the network not only to Ford UK, but across five Continents, to anyone involved with the manufacture of engines (Ladbrook and Januszczak, 2001). Since the initial development of the first model in Ford, c1980, there have been questions about the results of the model. The data from the model is occasionally not trusted, especially when they divulge results that do not support the experience-based decisions of managers and engineers. These key stakeholders require proof that the model accurately represents the behaviour of the respective lines in these cases. The proof however does not exist in an accessible document and the simulation experts knowledge of the assembly line behaviour is not enough to give them confidence in the results.

2.6 Assembly Line Specification

The model doubt held by the simulation stakeholders stems from conceptual interpretations of how the assembly line behaves. Building the conceptual model is part of the job of the System or Simulation Analyst. The conceptual interpretations of the assembly line behaviour manifest themselves in the logic interactions within the model. The proof of model accuracy can be provided by an Assembly Line Specification (ALS) that expounds the actual behaviour of the Lion Assembly Line (LAL). The ALS displays the actual behaviour of the line in terms of logic which can be compared to the model. Any gaps between reality and the simulation can be removed or justified using the specification. The simulation analyst will then have the confidence to state that the model behaves as the document description of reality. An ALS with the correct content could improve the understanding of the simulation model for all the users. Conveying increased understanding of the decisions and process required to build the logic of the real system into the model to all stakeholders could also improve both the simulation itself and the methodology required to build and maintain the simulation models in Ford.

The development of an ALS at Ford has been hampered by the fact that there is no awareness of a standard way of building the ALS. The users of the ALS may be at different skill levels and have different requirements to satisfy the needs of their simulation use. The difficulty to make the standard document within Ford is the result of these factors. If an ALS were to exist in Ford, the users would be able to know what logic is included in the model and how it works. It could assist the model builder by identifying any gaps in the logic so the model can be updated to truly reflect reality.

2.7 Chapter Summary

This chapter introduced the industrial context of Ford and drills down to identify the motivating issues in Ford to be addressed in this research. The chapter began by discussing the Lion Engine Assembly Line in Ford within the UK manufacturing industry, with an overview of the capabilities of the line. Simulation in the context of the Lion Assembly Line (LAL) and the concept of the FAST interface to Witness was introduced. The lack of confidence in the simulation model representation of the assembly lines' behaviour was noted. To identify whether this doubt is well founded, the compilation of an Assembly Line Specification (ALS) allows the identification of gaps and close correlations between the behaviour of the LAL and the simulated logic. The ALS is the documentation of the real system. This document could allow the simulation analyst to ensure that the simulation matches the real behaviour of an assembly line. Research on previous work can be used to identify whether solutions to these issues have been found within the context presented.

3 Literature Review

The industrial context and Ford problem requires the undertaking of research to identify the past and present work on the subject. Firstly, the simulation requirements are introduced in a manufacturing system context. The concepts and need for a specification document can be understood from this research. This chapter continues to present the content of a specification document. In the final section, the current state of simulation documentation is presented.

3.1 Simulation of Manufacturing Systems

The following sub-section clarifies simulation in the context of manufacturing.

3.1.1 Knowledge Requirements

Considerable knowledge of a manufacturing system is required to model it. The skills and expertise required to build simulation models can be the speciality of a systems analyst or a simulation specialist within an organisation (De Swaan Arons and Van Asperen, 2000). Knowing how much detail to include in the model is a key component of the simulation or systems analysts' knowledge. Importantly, knowledge on how to implement the model in a specific simulation package is essential. The simulation of a complete manufacturing system requires understanding of the whole system and its operational characteristics. Tours of the existing system, close analysis of drawings and review of work standards (description of work done) can be carried out to give a holistic appreciation of the system (Nordgren, 1995). Without a holistic knowledge of the assembly line and its components, models may not represent reality to an accuracy required. Important considerations when making simulation models are model boundary, level of detail and project scope. The model boundary and scope will determine what is in the model. (Carson, 2005)

3.1.2 The System or Simulation Analysts' Role

Simulation model development basically consists of two main activities (Carson, 2005):

- Data structure development and acquisition required by the model to behave like reality.
- Translation of the logic into language or representation required by the simulation package.

Less than 50% of a simulation analysts' time is actually spent on building the model, the other time is spent collecting and structuring input data, writing specifications and reports, experimenting with the model and presenting results (Rohrer and Banks, 1998).

Producing a simulation model can be decomposed into nine stages which must be documented. Nordgren (1995) suggested that nothing is 'real' when analysing a system until it is written down. The nine steps can be summarised in Figure 3-3:

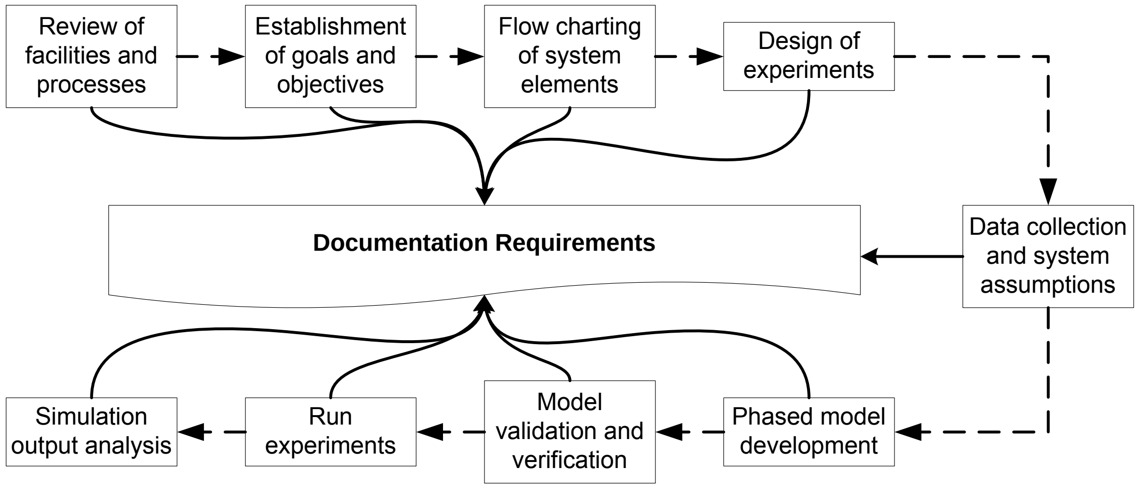


Figure 3-3: Nine Steps of a Simulation Project

Each of the stages in Figure 3-3 is recommended to be documented, however in reality this may not happen due to time and resource restrictions. Sharing and recording of information is difficult within companies especially if there are no standard approaches to follow. A documentation exercise tends to be carried out for a particular function and so is hard to transfer the knowledge to different people in other roles within an organisation.

3.1.3 Simulation Information Requirements

Systematically reviewing the real system is agreed by authors involved in discrete event simulation to reduce the probability of omitting vital information from the simulations model (Williams and Orlando, 1998, Carson, 2005 and Nordgren, 1995). The presentation of information agreed to be required follows:

<u>System Components</u>

Entire lists of all the elements and their operating characteristics should be made. The elements in the system may be machines, storage locations for WIP, work tables, tool locations or anything that is used to assembly the product in the context of this research. Product components, parts, and sub-assemblies should also be listed.

<u>System Resources</u>

Lists of all the system resources ensuring annotation of special operating characteristics assist with model building. System resources may be fork-lift trucks, Automated Guided Vehicles (AGVs), maintenance personnel and machine operators.

Operational Characteristics

As each system component is reviewed and notes of their operational characteristics should be made. Logs of any special processing logic and how operations interact with other elements of the system should also be kept.

System Terminology and Acronyms

This step clarifies exactly what the terminology is used to ensure synergy in the terminology used by the people involved in a simulation project. Most facilities have names or acronyms that are used to describe equipment or parts. These are noted and used throughout the simulation. A common vocabulary with the assembly line allows the model to be more familiar and realistic to the stakeholders.

The goals and objectives for the simulation project set the focus of the model. Asking questions to the users of the simulation and decision makers who use the output of the model to justify them (Carson, 2005, Nordgren, 1995 and Williams and Orlando, 1998)

3.2 Specifications of Systems

This section introduces the concept of specifications, focusing on the commonalities shared between software specifications and simulation specifications, the users and the uses.

3.2.1 Specification Overview

Simulations can be seen as a manipulation of a software package that accepts different inputs to give the required output using the existing framework of the simulation software code. The analogy of simulations and software coding enables the principles of software construction and documentation to be transferred to simulation documentation. A Simulation Specification Document (SSD) of a system can be broadly regarded as a written record of the model development and operation to serve as a communication tool for people who come into contact with the model. It gives a log of how the model was created and provides a method of verifying the quality of the model with the real system. The information contained in it should be adequate so that a simulation model can be systematically built. It is recommended that all the information used to build the model be recorded and used, even informal notes as they all help with understanding the rational behind the model. The process should be information greedy so that the document can follow all the steps needed to build the model. This will help prevent the document from becoming out of date (Gass, 1984). The specification of the real system, in this case the ALS can be considered a component of a SSD. The ALS is the record of the real system analysis component of the document (Highland, 1977).

3.2.2 Specification Need

Modelling manufacturing processes and managing the available information and data efficiently and consistently poses a problem. From as far back as 1977 to the present times, it is recognised that there was no standard system of documenting a simulation model (Highland, 1977, Lu et al, 2003). Historically there have been inadequacies in the quality and content of simulation documentation meaning that a user ignores the power of the simulation or make decisions based on degraded information. There may also be the risk that the stakeholders make incorrect decisions or pass on this responsibility to someone with more knowledge of the simulation, but with little awareness of the overall impact a poor decision will have on the wider organisation (Gass, 1984). A well written SSD helps make a simulation project successful. It is used to summarise the input data and the approach to build the model. It should be written for a non-simulation biased audience. There is the argument that the structure and format for the specification can be learned on the job and so there should be no standard as organisations are different (Rohrer and Banks, 1998). There are suggestions regarding the importance of documenting the development process for simulation models, but only few suggestions about how to document the model itself. This lack of a uniform way to document simulations can lead to poor and scarce documentation. This is despite the knowledge that a specification document increases the credibility of a simulation model (Law, 2005, Oscarsson and Moris, 2002).

3.2.3 Document Users

Documentation should be used as a communication tool between the various users of a simulation model and its outputs. It ensures that the model is fully understood and can be operated, maintained and updated presently and at some point in the future. It allows an external party to evaluate the model. Therefore the questions must be asked of the users as to what information they require in the document to use the model and maintain its validity with respect to the discussed requirements (Gass, 1984). A SSD communicates a set of assumptions to all simulation stakeholders and be modified so that all stakeholders agree with the document contents and what is going to be modelled (Carson, 2005). The document provides information to non-specialists about the simulation model that is easy to read and use. From the specification the user should understand what the simulation will do, how it will do it and why it should do it that way (Davis, 1986, Highland, 1977). It is suggested that there could be four types of SSD, one for the user, one for the analyst and one for the non-specialist decision maker who just wants an executive over view of the document and model. The fourth is a concise overview of whole document (Gass, 1984).

3.2.4 Document Use

There are many uses of simulation and software models. Software models and their specifications are used comparatively in the research due to the similarities between software coding and simulation language.

The SSD may be used when planning and carrying out maintenance on the model. The document describes the process for modifying the model and its data, the revalidation, update and maintenance responsibilities (Gass, 1984). The verification and validity of the model must be proved during its construction phase; this may be done with the SSD. The verification and validity of the SSD itself must be re-established whenever the model is changed (Carson, 2005). The formulation phase of the model is documented. This part of the document is maintained throughout the lifecycle of the model. The structure of the model may be modified over time and its description also updated. This must be initiated so that the simulation model is not updated without the correlating changes made within the SSD (Gass, 1984).

3.3 Simulation Specification Document Contents

This section presents the content of a complete simulation specification document.

3.3.1 Overview

A standardised document that explains how a simulation model was developed will aid the model to be understood, updated, re-used and inherited. Importantly the Simulation Specification Document should be clear and comprehensible to a variety of audiences within a manufacturing organisation (Oscarsson and Moris, 2002 and Lehman, 1977). Due to the document being read by different people within an organisation it should be written in the language of the assembly line so that non-simulation people can understand it. The SSD can be used to validate the simulation and the modelling methodology, therefore as much information as possible should be included and nothing used by the simulation should be omitted. There are four levels of a software specification document that can be defined and transposed to a SSD. The levels are completed in order giving a hierarchical structure to the types of questions, answers and presentation that are required to develop and complete the document (Davis, 1986). These hierarchical levels are common throughout different software and simulation applications of specification documentation. The specification document may be built with progressive levels of detail until enough information is contained to allow the computerised simulation model to be built.

The content of the levels are presented through the rest of this section.

3.3.2 Level 0

In this level general concepts of the model, domain applicability, outputs and intended use are stated. It can be derived from the feasibility phase of model development and describes the process used to determine the model function and its completion capability. In general it describes the stakeholders of the model, their roles and where the decisions made from the model will be used (Gass, 1984).

Purpose of the Model

Clarification of the purpose of the model is suggested by a selection of authors to be one of the primary requirements for any documentation and for the model itself. (Carson, 2005, Gass, 1984 and Nordgren, 1995). During this embryonic phase, discussions of the origins of the model idea can be documented.

Table 3-1: Information Suggested for Documenting the Purpose of a Model

Problem	Model	People
Background	Why modelling was considered?	Who initiated the model and Why?
Summary of what is to be accomplished in the study.	Why a model?	Who are to be the users and what their needs are?
Purpose	What is expected from solution?	Organisations and participants involved in the study
Definition of the problem and issues and objectives	How model and solution are to be used	
The theoretical and analytical rationale for its form in terms of the problem definition	A precise statement of what the model is supposed to do.	
Extent of problem	Recommended computer model solution and justification	
Requirements to be met	Organisations functions and systems examined	
General description of problem and decision environment		
Impact of problem and solution		
Important points		

The Model Scope

The model scope deals with how the model will be used what outputs are going to be analysed and what questions the simulation model itself will answer (Carson, 2005 and Gass, 1984). At this point an overview of project goals, specific issues addressed by the model and relevant performance measures could be given including (Law, 2005 and Nordgren, 1995):

- Goals and objectives of the simulation
- Intended use and users
- Issues investigated
- Issues that will be looked at by the simulation
- Model capabilities
- Model limitations
- Problem domain
- Restrictions on the use and range of the model

The Resources Required

Including the required resources adds to the value of the document by showing the thoroughness of it (Gass, 1984), such inclusions are:

- Computational and numerical analysis requirements
- Computer resources required
- Resource requirements (personnel, programs and facilities)
- The computing environment defined (interactive features and graphics)

The Key Performance Indicators of the Model

The specific problems and questions the simulation model is to solve needs to be clearly stated. Without these definitive statements it is almost impossible to determine the amount of detail required by the model to represent the real system. The statements are used to measures the performance of the model (Law, 2005, Carson, 2005 and Nordgren, 1995).

Model Use

Importantly, information and guidance on how to use the model may be required. Also the sources of information that were used to build the model will be helpful after the model has been built to gather additional information or prove information quality (Law, 2005). Other pieces of information could include (Oscarsson and Moris, 2002, Gass, 1984 and Nordgren, 1995):

- A plan of actions and schedule of activities
- A set of operating instructions for the user
- An explanation of the various options available in using the model
- Definitions of the experiments performed with the model

- Names of the system analysts and productivity engineers responsible for the models
- Notes about the syntax used and model structure
- Terms used and definitions of all ambiguous terms used in the model

3.3.3 Level 1

This level contains the models' functional content; the processes and their effects in the model as well as the algorithms and parameters used. The model inputs and its expected validation are also included at this level.

Data

The data phase of the model is important and must be documented. This part of the SSD documents the data required to build the model and is maintained throughout its lifecycle (Law, 2005, Richter and Marz, 2000, Gass, 1984 and Nordgren, 1995). It describes:

- Acceptable data ranges
- Assembly data elements
- Change-over times
- Constraints placed on an element due to another element
- Data collections and surveys performed
- Data element keys
- Data input procedures
- Data sources
- Data to specify model parameters
- Data validation procedures
- Detailed data needs as required by the model
- Downtimes
- Experiments
- General data requirements
- Input and output definitions
- Material handling interfaces
- Numerical and forecasting techniques to be used for parameter estimation
- Operation times
- Organisational and individual responsibilities for obtaining, updating and processing the data
- Part arrival information
- Summaries of input data
- The process for obtaining the data

The length of the list above demonstrates the importance placed on the data required to model a system. The authors range across subject areas and applications however the theme is that recording all the possible information around data is an important component of the SSD.

Validation

It is recommended that information required for the validation phase be included in the specification (Davis, 1986 and Gass, 1984), including:

- A description of the model validation plan agreed by the stakeholders
- Approaches and tests for validating the model
- Include tests of the model outputs in terms of comparisons to historical data, acceptability by the stakeholder (experiential or intuitive tests) and statistical measures
- Sensitivity, robustness and other evaluations required
- State and explain the gaps and correlations between reality and the real system

3.3.4 Level 2

Information contained in Level 2 of a SSD could describe the logic structure, events, algorithms and process flow so that the complete system components and their operational aspects in the model are clearly obtainable. Included in the document should be assumptions, limitations and details of the inputs.

Real Life Overview

The whole system layout, sub-system descriptions, system components, operating procedures and the flow of the parts through the system can be included (Law, 2005, Gass, 1984 and Nordgren, 1995).

Assumptions and Rational

The variables, Part attributes and functions must be fully defined (Nordgren, 1995). The processes that make up the model, including any parameters and algorithms that characterise them such as flow or connectivity are said to be required in a SSD (Davis, 1986). An important part of the document is agreed to be the simplifying assumptions, rational and justifications for steps taken and decisions made during model construction. Hypotheses and restriction may fit well into this stage. Definitions of the limitations of the model are also important to be included (Davis, 1986, Gass, 1984 and Nordgren, 1995).

3.3.5 Level 3

The inclusion of the intricate logic of the model should be included at this level. The logic defines the dynamic behaviour of the model during simulation experimentation. Detail of the logic that was used when creating the simulation model is important for trouble shooting and modifications. The logic relationships and interactions can be represented at this level (Davis, 1986 and Gass, 1984).

3.4 The State of the Art of Simulation Specification

In this section the analogy between simulation specification and software development specifications is investigated further. Recent developments in simulation information extraction are discussed with older methods. Finally the evolution of simulation specification documenting is presented.

3.4.1 Software Specification Analogy

Comparing to software specification development in the literature researched, there is less evidence for a standardised approach to compiling simulation specification documents. Unlike SSDs, software development has associated standards to assist programmers with their approach. Particularly when focusing on the requirements to construct software. There are several standards for a Software Requirement Specifications (SRS), such as the IEEE standard (IEEE, 1994). It defines the content of the document and the topics that can be tailored to a specific application. The SRS document denotes what the software requires to run, some of the underlying principles of the software and introduces a user to it (Law, 2005). These property types are similar to those identified for the inclusions in a simulation specification. A new approach to software engineering has been developed, the unified approach, which promotes component-based architecture and the use of UML. The approach can be used to specify simulation models to describe the essential structures and dynamics of a simulation model to be built. Stakeholders obtain a specification document parallel to building the simulation model (Richter and Marz, 2000). The drawback with following the software specification route raises itself when considering the wider model stakeholders who are affected by the results. Following the UML approach may use a high level of detail that looses communicative power when considering high level users of the document and simulation.

3.4.2 Simulation Extraction

There have been many different simulation protocols developed (Abrams et al, 1991), provided by many vendors such as Witness, Quest and Arena to name a few. They have there own requirements for information and data to utilise the software. The specifications for the simulation of the system under study could vary between applications of the specification in the various software frameworks. The National Institute of Science and Technology, US (NIST) is developing an XML based simulation interface containing a generic simulation data specification with the aim of filling the void in exchanging re-usable simulation information. XML is a simple, flexible, text based mark-up language for documents containing structured information (Lu et al, 2003). Boeing Commercial Airplanes was used as case to test the NIST standard specification. Previously they had been using a specification document of their own development but without the level of detail proposed in the NIST document. The document increased their efficiency of creating future simulations. The NIST document encompasses more data types and groups than was necessary for the Boeing simulation (Lu et al, 2003). The NIST document is an XML based tool that is not user friendly to a wider audience within a company. It is developed mainly for the system analyst to build the simulation not as a communication tool.

Accepting the complexity of constructing simulation models has allowed research to be carried out on 'clever' ways to construct models. A Knowledge-Based Model Construction (KBMC) system can be used to automate information extraction from experts. The KBMC system extracts a model specification from the user by posing questions and allowing the user to make selections from pre-defined menus. The KBMC user describes what the model is to do in response to queries driven by the rules which guide the users' interaction. The system uses Artificial Intelligence (AI) programming in the background to order the extraction of information from the user. The content of the questions is controlled by the previous answers (Murray and Sheppard, 1987). This simulation support tool is focused towards the simulation and domain experts. The paper presents the KBMC as an information extraction tool, not a communication tool. The majority of the level 2 and 3 (Sub-section 3.3.4 and 3.3.5) information could be included in the KBMC; however the high communicative strength of the Level 0 and 1 content would be omitted.

3.4.3 Evolution of Simulation Documentation

Simulation specification documents appear to be evolving from pure documentation principles, solely recording the pre-simulation construction work, simulation building processes and simulation utilisation steps. Simulation documentation is heading towards an on-line digital guide and documentation system to support modelling applications within an organisation. The nature of the 'on-line' method of documenting the simulation models enables specifications to be searchable by stakeholders who share access to a central database (Hansona et al, 2006).

The online or web-based documentation to accompany a simulation can contain much information about the structure, content and results of experiments. The experimental results and analysis can be extracted from the central database as pure data. Animations showing the graphical simulation interface enabling a user to understand the flow of parts through the system are possible in an online version. This basic methodology may be extended to a larger scale using web-technology principles by enabling users not only to look at the documentation of the simulation but also to run simulations remotely from different locations. Using a web-server methodology allows different user access levels to focus modifications to the specific needs of a stakeholder prevents original model corruption (Narayanan, 2000). The result of combining the documentation and simulation in a web-based tool forms the basics of a distributed simulation (Morse et al, 2004).

Documentation that contains experimental results can be shared between stakeholders by applying restraints whereby the results of experiments run by users are published onto the web-based SSD. The results can then be searchable and shared among users (Hansona et al, 2006). The ability to begin to standardise simulation approaches draws closer when using web-based formats. There are standards of web communication already drawn up by the World Wide Web Consortium (W3C). The standards in existence for web-based communication are well known within industry. However, the more specific distributed simulation standards are still in their early stages of development. Distributed simulations encompassing the many information requirements with the inclusion of the simulation itself may be in its infancy however Morse et al. (2004) anticipate that web based modelling and simulation will continue to grow.

3.5 Chapter Summary

The literature review aimed to capture a cross section of research on the subject of simulation and specification documents. Research material was obtained covering different industries from the Department of Defence in the United States (Law, 2005 and Davis, 1986) to manufacturing system life cycle simulation in Sweden (Oscarsson and Moris, 2002). Older sources of information benefit this research by highlighting the issues concerned with the lack of documentation have been around since 1977 (Highland, 1977). The review of current developments in this field ensures the research approach followed, results and recommendations are relevant for Ford in the current manufacturing simulation environment.

Clarity from research confirms that specifications enhance simulation projects and those decisions based on the simulation outputs. Specification documents contain large volumes of information which can be broken down into levels of detail. The different levels of a Simulation Specification Document (SSD) are relevant the requirements of different stakeholders. Current work on specification documents (Hansona et al, 2006, Lu et al, 2003 and Morse et al, 2004) indicates they are moving away from pure model support and justification towards interactive user manuals, guiding simulation stakeholders through the specification to extract the required information.

In the cross section of research reviewed, there has been no specific research concluded on Assembly Line Specifications. The requirement of documenting the simulation approach includes, but does not focus on, specifying the real system. Critically there is no evidence found of a standard approach to documenting the analysis of the real system. There is correlation between authors on the recommended inclusion of information within the specification.

The literature review when concluded and combined with the industrial context facilitates the formulation of the industrial problem, research aim, objectives and methodology of this research.

4 Research Methodology

This chapter defines the methodology used to solve the industrial problem, defined in the first section. The second section identifies the aim of the solution to resolve the problem and the objectives that are required to achieve this aim. Finally the methodology is given with a foreword to the target deliverables from each stage.

4.1 Problem Definition

As stated in Chapter 2, there is currently a perceived gap existing at Ford Motor Company between the actual engine assembly line behaviour and the simulation logic that represents it. The perception of the gap is shared by numerous stakeholders and has resulted in a lack of confidence in the simulation output data used for decision making. The simulation analysts at Ford currently have no means to prove otherwise. There is no Assembly Line Specification (ALS) in existence that demonstrates gaps or similarities between the Assembly Line behaviour and the simulation model logic.

The review of literature provides evidence that there is currently no standard way of documenting a simulation model. The simulation model at Ford is used in conjunction with specially developed tools. This adds an increased level of required understanding and uniqueness to the issue as these tools are only used in Ford. The recommended information to incorporate in a Simulation Specification Document (SSD) to increase complete confidence in a simulation and its outputs is well documented in literature. However the content requires development in the context of the Lion Assembly Line (LAL) and considering stakeholder requirements.

The ability to analyse the fully operational Lion Assembly Line, the simulation tools and techniques place the researcher in a unique position to investigate the development of an Assembly Line Specification. The unique view point of the researcher also allows the critical comparison of the current simulation philosophies and the potential improvements to the simulation strategy from the application of a SSD.

4.2 Aim and Objectives

A potential solution allows the following aim to be achieved:

"Increase Confidence in Simulation Models of the Engine Assembly Lines within Ford"

The industrial problem solution targets the development of documentation to specify the real system in sufficient detail to identify gaps and close correlations in the underlying logic of the simulation. To complete an Assembly Line Specification and achieve the aim the following objectives have been established:

1. To analyse and represent the Ford Lion Assembly Line logic.

2. To verify and validate representations of the Lion Assembly Line logic.

3. To develop an Assembly Line Specification.

4. To critically analyse the use of the Assembly Line Specification to improve the simulation strategy within Ford.

4.3 Research Methodology and Deliverables

To achieve the objectives a process consisting of four stages is used. The first stage covers the methods and results of the Lion Assembly Line (LAL) analysis. The second stage presents the validation of the results and diagrams from Stage 1. The third stage shows the development of the Assembly Line Specification (ALS). Finally, in Stage 4 the potential improvements to the simulations methodology at Ford using an ALS are examined.

4.3.1 Stage 1: Lion Assembly Line Logic Analysis

The purpose of this stage is to understand the behaviour of all the components of the LAL that are modelled and used in the simulation.

The analysis of the LAL line is split into two methods. Firstly the assembly line is analysed and information collated of logic its constituent components. Secondly, the logic information is analysed and standardised to find common representations of the components of the line.

The deliverables of this stage are draft logic diagrams and a detailed knowledge of the LAL behaviour.

4.3.2 Stage 2: Logic Diagram Verification and Validation

The purpose of this stage is to verify and validate that the analysis of the system is complete and truly represents the behaviour of the LAL. Matching the analysis approach and LAL logic to the requirements of the simulation allows accurate comparison between them.

The logic representations are introduced to three different views of the assembly line. The first is from the perspective of the control system to allow the logic decomposition of the LAL to a fundamental level. The second perspective is from the simulation side; the information from this view point ensures that all the simulated behaviours of the LAL are collected in the analysis stage. The third and final outlook is from the perspective of LAL engineers, where agreement that the important components that affect the real system have been accurately recorded is achieved.

The deliverable from this stage is complete verified and validated representations of the LAL logic.

4.3.3 Stage 3: Assembly Line Specification Creation

The purpose of this stage is to develop the Assembly Line Specification (ALS) to contain and expound the logic required to identify gaps and correlations between the simulation logic and the behaviour of the Lion Assembly Line.

The methodology to carry out this stage is threefold; firstly the simulation stakeholder, literature, LAL analysis and V & V inputs define the content of the ALS. The ALS framework development is carried out in the second method. Finally, the corroborated information and developed format are combined to produce the specification documentation.

The deliverable of this stage is an Assembly Line Specification.

4.3.4 Stage 4: Assembly Line Specification Utilisation

The purpose of this stage is use both the ALS and the simulation model to identify gaps and correlations between the assembly line and the simulation model in order to pinpoint possible improvements to the Fords simulation strategy.

To complete this stage two methods are required. The first is to hold collaborative meetings with the simulation experts in Ford to use the ALS to review the assembly line simulation to identify gaps and close correlations between the simulation logic and behaviour of the LAL. The second method is to assess the impact of the specification on the current simulating practices within Ford.

The deliverables from this stage are identified gaps and correlations between the simulation model and the LAL. Table 4-2 summarises the four stages introduced.

Table 4-2: Summary of the Research Methodology and Deliverables

	Title	Purpose		Methods	Deliverables
Stage 1	Lion Assembly Line Logic Analysis	To gain an understanding of the behaviour of the real system	**1**	Gather Logic information from the assembly line	Diagrammatic Representations of the Lion Assembly Line Logic
			2	Develop representations of gathered Logic	
Stage 2	Logic Diagram Verification and Validation	To ensure true representation of the behaviour of the assembly line	**1**	V & V from Control system viewpoint	Reviewed Logic Representation of the Lion Assembly Line
			2	V & V from Simulation viewpoint	
			3	V & V from Assembly viewpoint	
Stage 3	ALS Creation	To identify the specification document framework	**1**	Gather Stakeholder Input	Assembly Line Specification
			2	Develop document Framework	
			3	Build Document from previous stages	
Stage 4	ALS Utilisation	To identify improvements to the existing simulation models and methodology	**1**	Collaborative Review of existing simulation model	Identified Gaps and Correlations
			2	Comparison of Ford's Simulation Strategies	

In this chapter the research methodology was introduced. The proceeding chapters discuss these stages and processes in further detail, also identifying the results, issues and key findings of each stage.

5 Lion Assembly Line Logic Analysis

This chapter presents Stage 1 of the methodology introduced in the previous chapter. This chapter conveys the understanding gained of the Lion Assembly Line (LAL). The completion of this stage gives initial representations of the LAL logic to be validated. In the first section the approach taken is described. Using this approach, components of the LAL are then presented in the second section. Thirdly these results are analysed, identifying important issues. Finally, the interpretation of the collected information into the flow representations is expressed.

5.1 Analysis Considerations

This section presents important considerations during the logic analysis and representation stage.

5.1.1 Scope of Assembly Line Data Analysis

Assembly line data analysis is not required as this data is trusted more than the model logic. The data provided in the model comes from Quality, Control and Productivity Engineers (possible model stakeholders). The data is more easily modifiable to match reality. The fact that the data exists in the model is recognised but not the accuracy of it. The data is a vital component of simulation, the omission of data is used to keep the model simple. However, if the omission of a data field means that the simulated performance of the assembly line is inaccurate then the model can be said to be logically incorrect. An assumption of this work is that the accuracy and magnitude of the data already contained within the simulation is correct. The scope of this research is the analysis of the logic of the real system.

5.1.2 Logic Complexity and Depth

The LAL is a complex system with many interactions as discussed. To simplify the analysis of complex systems it is beneficial to break it down into varying levels of simplicity. A high level system analysis may begin with an overview of the system; from this level the interactions observed appear complex, numerous and confusing. However, these complex interactions, when viewed at a low level, are less numerous and simpler. The logic of the system can be broken down and approached in a similar manner. Deep analysis of the logic of the system is enabled by breaking down the logic into levels and zooming in on a particular section of interest. Deep analysis of the logic is carried out by observations of the effects of input and output signals between sensor, control system and actuator. The knowledge and understanding of the mechanisms at this low level gives a strong foundation to build the representations of the whole system from. This enables the confident identification of logic gaps at higher levels between the LAL and the simulation.

5.1.3 Logic Extraction

The logic must be extracted from the analysis of the assembly line. To do this questions are asked of the real system, such as:

- What if x happens?
- Then what happens?
- What else happens?
- What happens when an activity finishes?
- What happens when a Part enters the element? etc.

If the answers to these questions are not evident then people who know the real system are asked for their input. The types of people questioned are Operators, Team Leaders, Process Engineers, Productivity Engineers and Assembly Engineers.

5.1.4 Observation Interpretation

The assembly line is analysed by observing what is visibly happening to the parts in the system. Issues may arise due to differences between an observers' interpretation of visual stimuli. Interpretations in human brains are based on their past experiences; different people can have a varied interpretation of the same sensory stimuli, producing different responses (Alder and Heather, 2003). For example, can two heads or a vase be seen immediately in Figure 5-4?

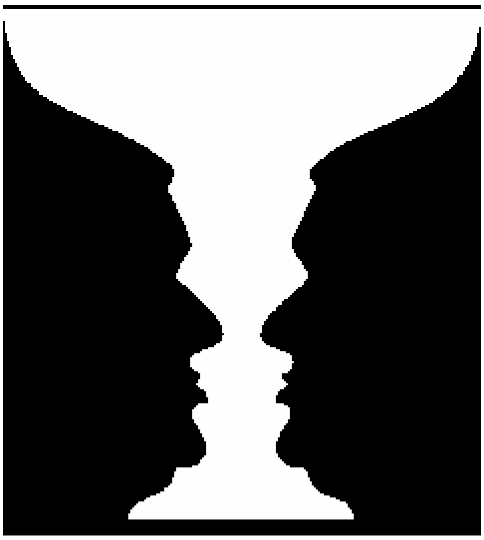


Figure 5-4: Demonstration of Interpretation Issue

(Shannon, 1975) has described the analysis of a real simulation system an intuitive art. The results of systems analysis is open to interpretation and are based on the observers' conceptual impression of the system under study. A system analysed by two people may not have the same interpretation realised. Verification and validation in Chapter 6 will be carried out on the observation approach to homogenise the interpretation of the LAL behaviour.

5.2 Lion Assembly Line Logic Analysis

This section defines the tools and techniques used to collect logic information from the LAL. Analysing the LAL is carried out before looking at the simulation model. This prevents a bias towards the methods used in the simulation model. Approaching the study in this manner allows the interrogation and representation of the real line to closely match reality.

5.2.1 LAL Analysis Tools

<u>Work Standard</u>

The work standard is used to identify the operations carried out on parts in the system. The work standard also provides Ford terms and language used on the line. Work standards are also used when documenting the assembly line as it provides references from the real line used when visiting at later date.

<u>Layout</u>

The assembly line layout is annotated during observations to enable a ‘virtual’ walk through of the LAL when away from the Facility.

<u>Assembly Worker Input</u>

While walking around the line team leaders are on hand to give advice and real input into the assembly line mechanisms. The information given by the team leaders is validated with different people to reduce the possibility of biased responses.

5.2.2 *Section Approach*

Observing the real system means looking at an automation component level of detail. This requires close observation and knowledge of standard uses of sensors, control systems and actuators. The assembly line is observed, notes taken and sketches of different scenarios made. Notes are taken looking at what action the components of the assembly line are performing. Sections of the LAL are observed by analysing the flow of parts through them. The appearance of an example LAL section, its components and the flow of parts through the section is shown in Figure 5-5:

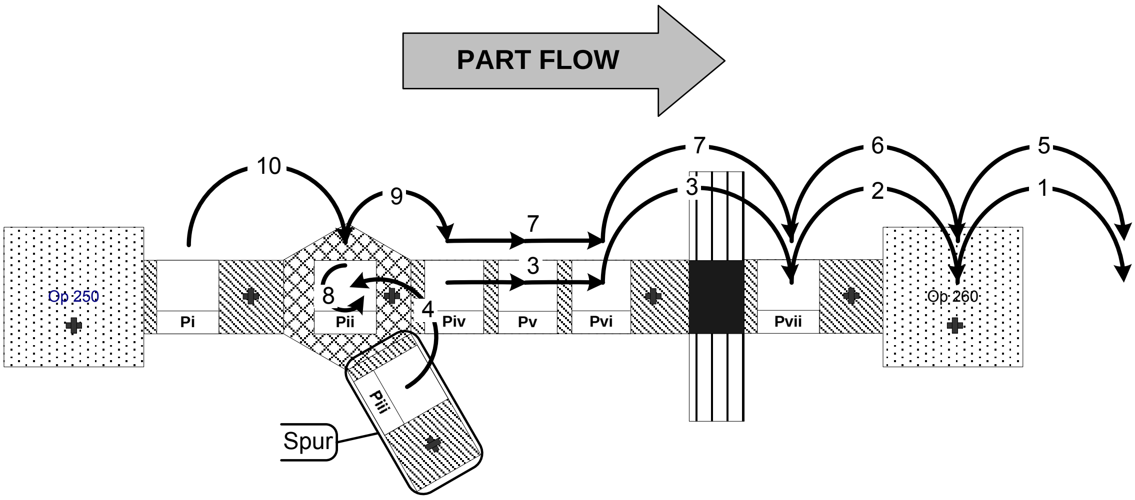
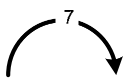
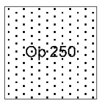
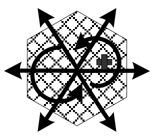
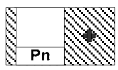


Figure 5-5: Section of LAL Showing Part Flow

Figure 5-5 depicts an example scenario containing parts at all the positions (Pn), in Op 250 and Op 260. Table 5-3 contains the legend of the sketch.

Table 5-3: Scenario Sketch Component Key

Name	Part Flow Arrow	Stop	Operation	Divert	Conveyor	Walk-Over
Sketch						
Description	The arrow represents the movement from one element to the next. The number indicates the step number.	This is the point on the element where the part is actively stopped before it can proceed to the next element.	The part is stopped and an operation performed on it.	The part is orientated to the required exit.	A conveyor has one Stop and can hold ‘n’ parts. Pn is the position on conveyor that holds a part.	Employee Walk over section of conveyor. (Not Classed as an element)

The scenario depicted in Figure 5-5 using the components described in Table 5-3 shows the injection of a Part into the line via a Divert. The detail of the movement steps is described in Table 5-4:

Table 5-4: Detail of Part Flow Steps from Scenario Sketch

Movement Step	Description
1	Operation 260 Finishes. Part leaves Operation.
2	Stop releases Part to Operation 260
3	Stop releases Part to Pvii. Parts on position Piv and Pv also move. Part from Pv is stopped by Stop at position Pvi.
4	Stop releases Part from (Spur) Piii to Pii.
5	Operation 260 Finishes. Part leaves Operation.
6	Stop releases Part to Operation 260
7	Stop releases Part to Pvii. Parts on position Piv and Pv also move. Part from Pv is stopped by Stop at position Pvi.
8	Part is rotated on Divert
9	Stop releases Part from (divert) Pii to Piv.
10	Stop releases Part from Pi to Pii.

An observation of the Part motion through the section gives a logic overview from a high level of the Part progress through the components of the LAL. To analyse the assembly line more deeply it can be broken down further to reveal lower levels of logic.

5.2.3 Elemental Approach

Observation of the LAL is carried out with the intention that it can be broken down into elements. Elements in this context are immovable parts of the system. The communication between them can be Part transfer or interactions through the control system, which is itself considered a non-moveable entity (Van Der Zee, 2006). Elements are repeatable components of a system that share properties. An example of an element could be the operations shown in Figure 5-5 and Table 5-3. This approach is recognised to produce reusable components (Richter and Marz, 2000). Observing and recording commonalities of components enables the identification of system elements. The identification of reusable components enables the system to be broken down and analysed at the level required to fully map the LALs logic. Therefore an element in the definition of this research is a component of the LAL (or simulation) that has a family of properties which make it unique from others. Any components sharing these unique properties will fall into this element family. The elements can be referred to as the repeatable building blocks of the assembly line (and simulation). The elements do not have to be ‘real’; they may be conceptual elements that are used to ease simulation modelling. Figure 5-6 shows that there are also other defining components to an element.

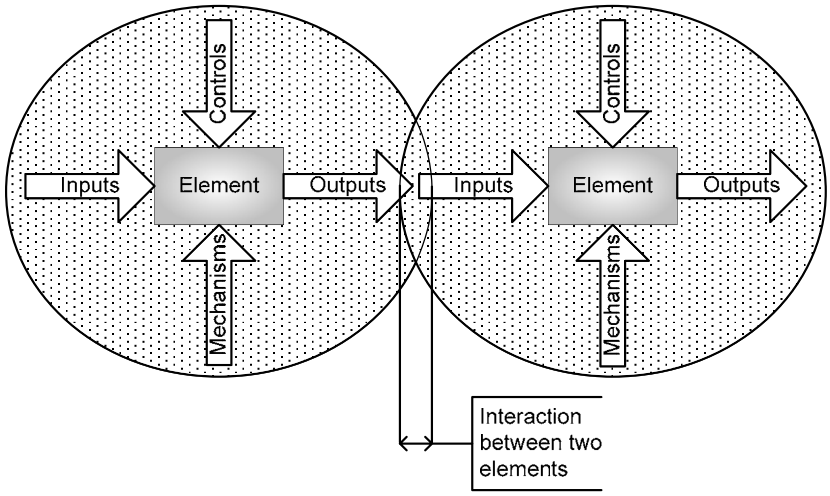


Figure 5-6: Element Properties and Interactions

From Figure 5-6; the controlling information of the element is their associated data parameters (such as Cycle Time, CT), the mechanisms are the processes that occur within the element allowing the input to output transformation. The inputs and outputs of an element depend on the way in which the element is being analysed. They could be Parts and/or control signals. The flow of a Part through each element is built of events and processes that change the state of the Part as it travels through the element. This event based approach is used to analyse what happens to an element (Carrie, 1992). The start of an activity is observed and the cause of an event is (attempted to be) determined. The end of an event or scenario and the results of its completion are observed.

5.2.4 Element Interactions

An in-depth appreciation of all the elements gives an understanding of the complete system. With an understanding of the elements, the interactions between them can be built. The element interactions in the simulation model represent its dynamic behaviour. Without the interactions the model would be static as there would be no part flow between the elements. The elements would be frozen in time at the beginning of their cycle (initial conditions) with only static properties. The start of a cycle is initiated by an input signal from the control system or the arrival of a part. The completion of the event occurs when the time to complete a process has elapsed. The interaction can be with adjacent elements and others throughout the line. For simplicity, the assumed interaction boundary of an element is where the output of one element becomes the input of another, depicted in Figure 5-6. A different view point of the system is required to look at these interactions. Shifting the viewpoint from observing the inner element to its extremities allows the observation of the effect the element has on its surroundings, this shift builds an increased global understanding. In systems analysis it is important to be flexible and have the ablity to shift perspectives to understand the system fully (Rohrer and Banks, 1998).

5.3 Lion Assembly Line

The actual Lion Assembly Line and Platen described in this section are two examples of important LAL concepts; other concepts used are described in Appendix B.

5.3.1 The Lion Assembly Line

The assembly line is in a configuration composed of different U-Sections as can be seen from a high level in Figure 5-7. The core components of the line are moving roller conveyors. This conveyor follows the bold lines indicated. The conveyor goes through all identified elements (Figure 5-10).

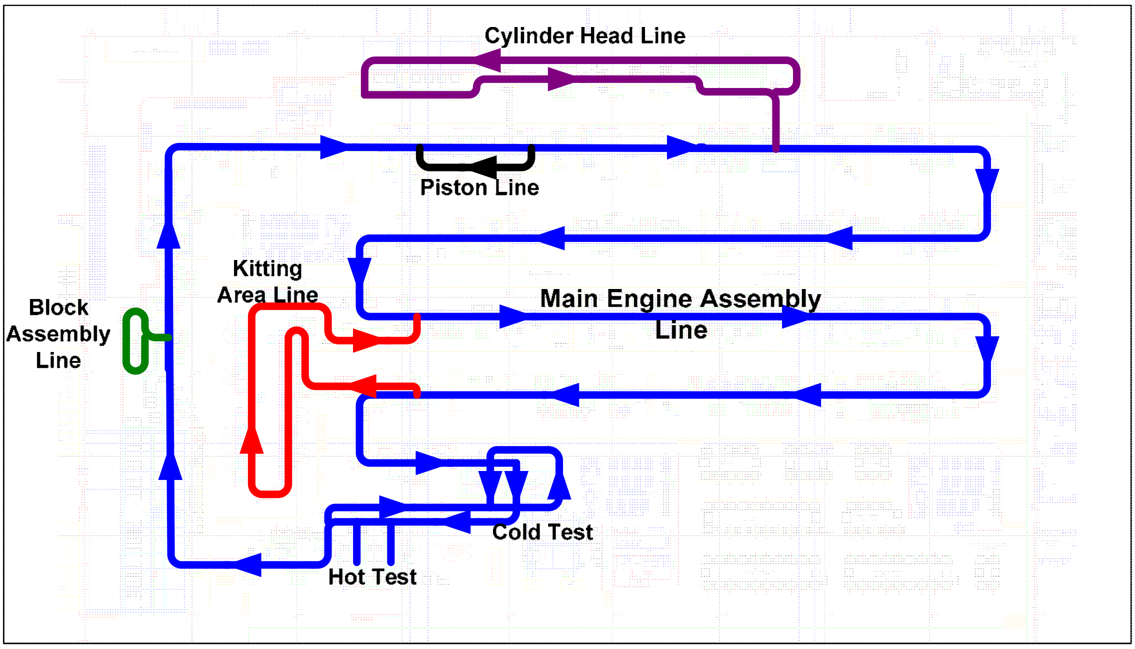


Figure 5-7: Lion Assembly Line Showing Main and Sub-Lines

Figure 5-7 shows that the complete Lion assembly facility is composed of a main and sub-lines. These sub-lines prepare sub-assemblies to combine onto the engine platen (sub-section 5.3.2) on the main line. These sub-assemblies are prepared in the correct sequence to match up with a corresponding engine type on the main line.

5.3.2 Parts and Platens

All the derivatives of engines produced on the LAL follow the same loop with variations in some operations. The engines and sub-assemblies that flow on the Block, Head, Kitting and main lines are mounted on Platens. The Platen is a device that allows the components to be mounted on the moving conveyor and manipulated in operations or by specific pieces of automation equipment. Operations can be carried out on the Platen by stabilising the whole device or removing the component and stabilising it within the operation. An example of an engine block and Platen is shown in Figure 5-8.

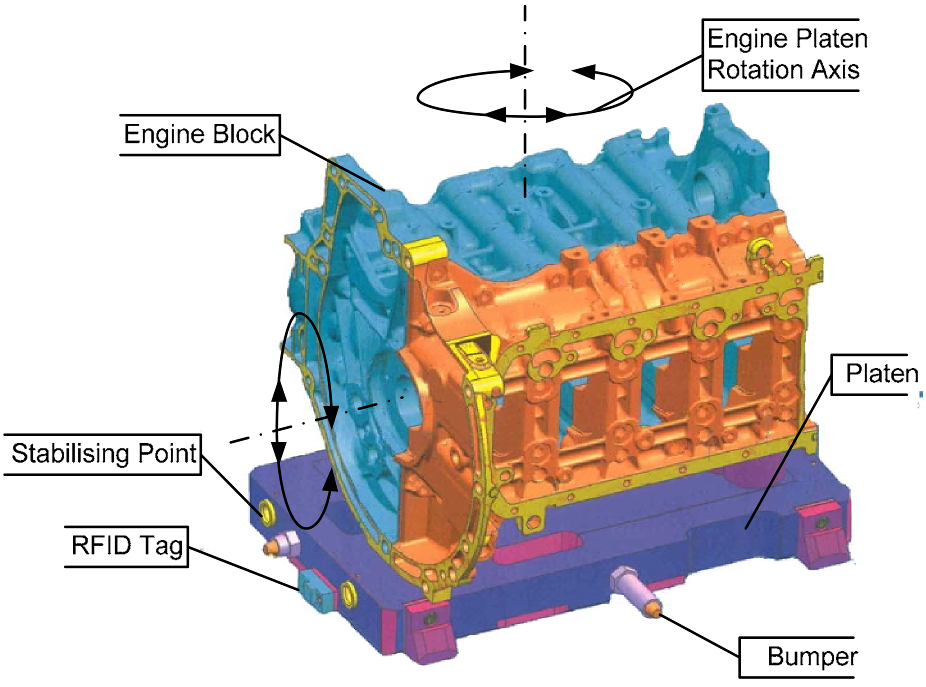


Figure 5-8: Engine Block Mounted on a Platen

The Platens used to mount the whole engine in the LAL are more complex than this example as the engine can be orientated on the Platen through different rotational axis exemplified in Figure 5-8. This allows the complex assembly procedures to be carried out efficiently and ergonomically by the operators.

5.4 Analysis of Results

In this section the elemental approach is applied to the observations of the LAL.

5.4.1 LAL Element Construction

The sketches made of the LAL, its components and descriptions of the Part flow are analysed for commonalities enabling decomposition of the line into elemental components. The elements observed commonly contain a Conveyor and a Stop. The conveyor is used to transport the Part through the element; the stop prevents a Part from moving further along the conveyor. The stops are required as the conveyor is constantly moving during working hours. Using these observations the initial sketches are broken into elements with interaction boundaries as shown in Figure 5-9:

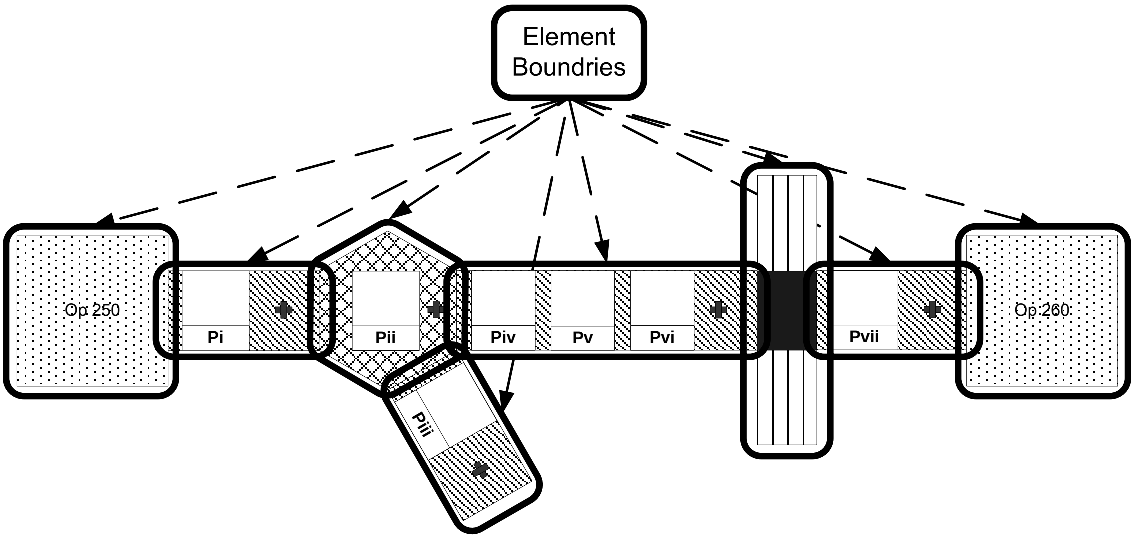


Figure 5-9: Element Boundaries of Example Section Scenario

5.4.2 Element Boundaries and Initial Conditions

Element boundaries set the scope of the information required to define the element. Part of the element boundary is its initial conditions. This start state is a conceptual interpretation of the real system. The initial conditions can be set freely, however, it is more systematic to apply them when the element contains no parts. The initial conditions differ for each element however some commonalities are shared. One of the benefits of the elemental approach to analysing the manufacturing system is that each element of the assembly line has a common denominator, a Platen, which passes through each element. The actions performed on the Part during an event can be observed on platen. The vast majority of elements have stops on them. Operations use them to stop the Platen so that the engines can be worked on. The stop prevents the Part from travelling through the element. It is intuitive to set the element boundary limits at the point where a part enters the element and at the stop that prevents a part from leaving the element. There are some anomalies to this approach as some elements do not have stops on them and others where the conveyor stops. These however are common for a similar appearing element in the real system and hence can be grouped together to define an element. From this intuitive approach the elements and there families are shown in can be defined.

5.4.3 Hierarchical Nature of Observations

The inheritance levels were observed to be operations that change the appearance of a Part and automation equipment that transports the platens through the system. The inheritance is determined by the visual properties of the assembly line components and the actions it performs. Figure 5-10 shows the inheritance hierarchy:

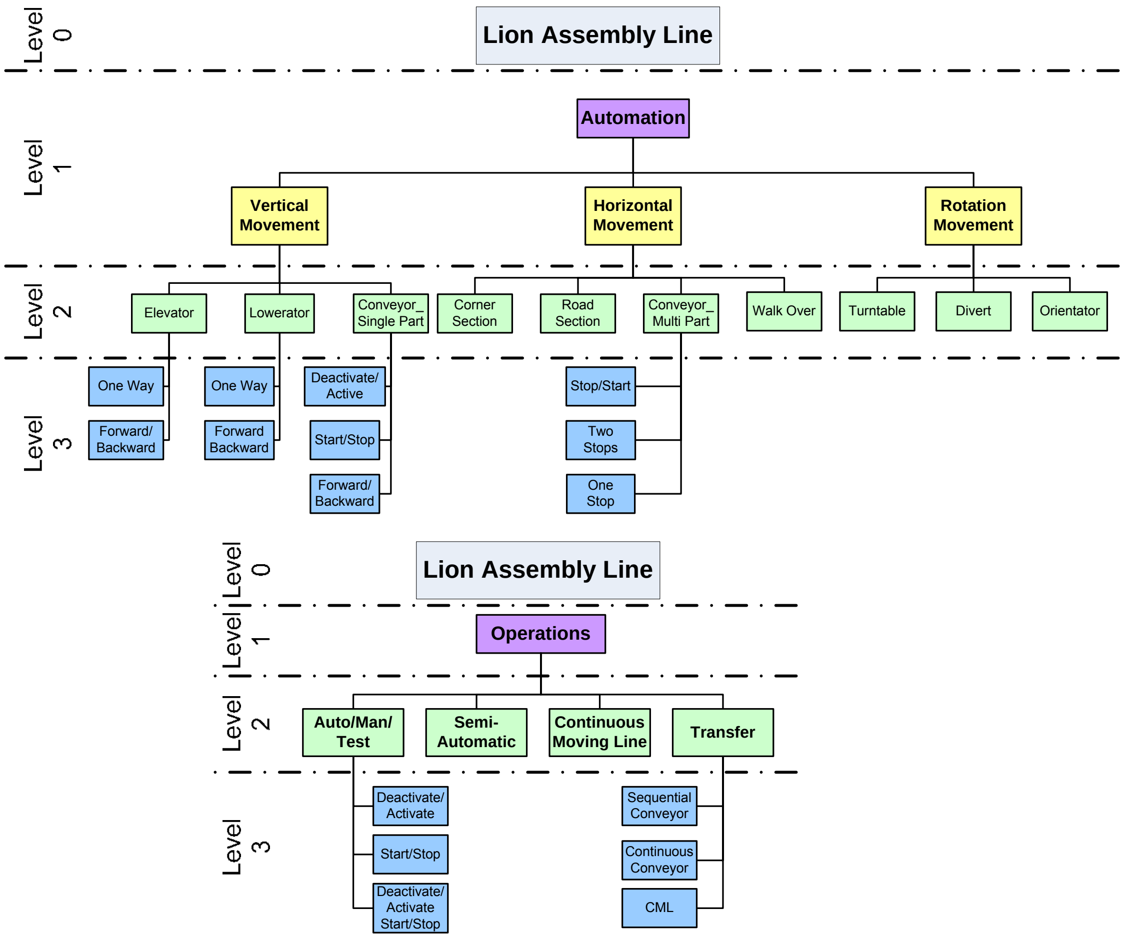


Figure 5-10: Elements Defined from Real System Analysis

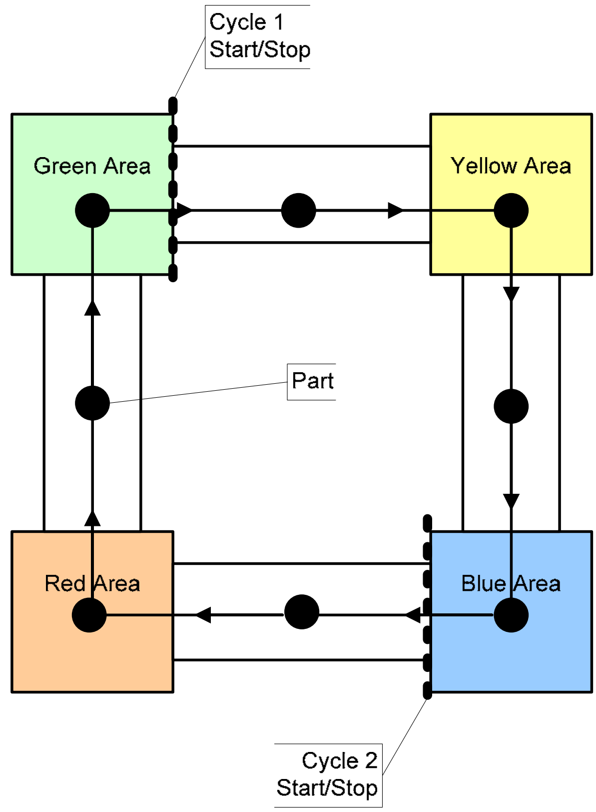
Figure 5-10 shows the object hierarchy of the elements identified from the real system. It shows the composition of the assembly line is built from common components. The assembly line components are grouped into different levels that share inherited properties of the parent level. Level 2 shows the identified elements of the real system and how they are associated with the assembly line by moving up the hierarchy. The elements at Level 3 inherit specific characteristics from the parent Level 2 plus some that make them unique. Level 3 is a deeper level of analysis from the observation of the actions that are performed on the common denominator, the Platen. These actions begin to appear common within the elements. This identifies that there may be a common way of representing what happens within an element to change the state of a part.

5.4.4 *Cyclic Behaviour of Elements*

Observation of the elements produces easily identifiable cyclic behaviour. The cycle is observed from the same point, the point can be selected at any position of the element activity and observed back to this point. The cycle will continue to occur due to an initialising action. Setting this start position is freely open to interpretation of the researcher. There are conceptual issues with setting the boundaries and the initial conditions of an element. The boundaries of an element depend on the interpretation of the observations of the system. The conceptual boundaries of the start conditions can be set by moving the start position, that is, the position where the cycle time clock is started and observation of the element begins. This can be simply illustrated using Figure 5-11:

Part Flow Cycle 1

Time	Start - Stop
1	Green - Yellow
2	Yellow - Blue
3	Blue - Red
4	Red - Green
7	Green - Green



Part Flow Cycle 2

Time	Start - Stop
1	Blue - Red
2	Red - Green
3	Green - Yellow
4	Yellow - Blue
7	Blue - Blue

Figure 5-11: Conceptual Element Start Position

It can be seen from Figure 5-11 that although the parts go through the same loop over the same amount of time there can be different starting conditions set depending on the view of the analyst. The complete Part flow does not change, but the interpretation affects the start and position of the Part at different elapsed times. The starting point in this research is set using the standards employed at Ford for measuring the operation time. This standard is the elapsed time from when a part enters an element to the next part entering the element.

5.5 Representation of Collected Data

This section presents the process carried out to create representative flow diagrams of the observed logic and element interactions.

5.5.1 Flow Diagram Process

Standard flow diagramming techniques are used as they can readily be understood by the vast majority of people, they are simple and do not require any specific equipment to make them. Appendix A gives and overview of the Flow diagram standards employed. The vocabulary used in the flow diagrams is chosen to closely match the language used in Ford and ease diagram communication. To begin to represent the flow of the parts through the element and hence the logic that an element uses to transform or transport the Part is diagrammed. The following procedure was used to build the logic diagrams:

Step 1: The visible components of the elements are listed.

Step 2: The actions and events that take place to change the state of an element are listed in order.

Step 3: The vocabulary is set by selecting unambiguous terms that have been observed from the assembly line, simulation and work standard.

Step 5: The important initial state of the element is identified and recorded.

Step 6: The Part flow and decision points for an element to change state are identified.

Step 7: The process that can begin due to the completion of a previous event is recorded.

Step 8: Iterations of Step 6 and Step 7 are continued until a Part has physically left the element.

The flow diagrams must communicate the logic simply and unambiguously for the gaps and correlations between the LAL and simulation to be identified.

5.5.2 *Standardised Logic Flow Representation*

Using the methodology from Sub-section 5.5.1, the information gathered from the real system is analysed. Logic diagrams were sketched for the elements. During this process there were common events, actions and queries identified which can be generalised for the elements as show in Figure 5-12:

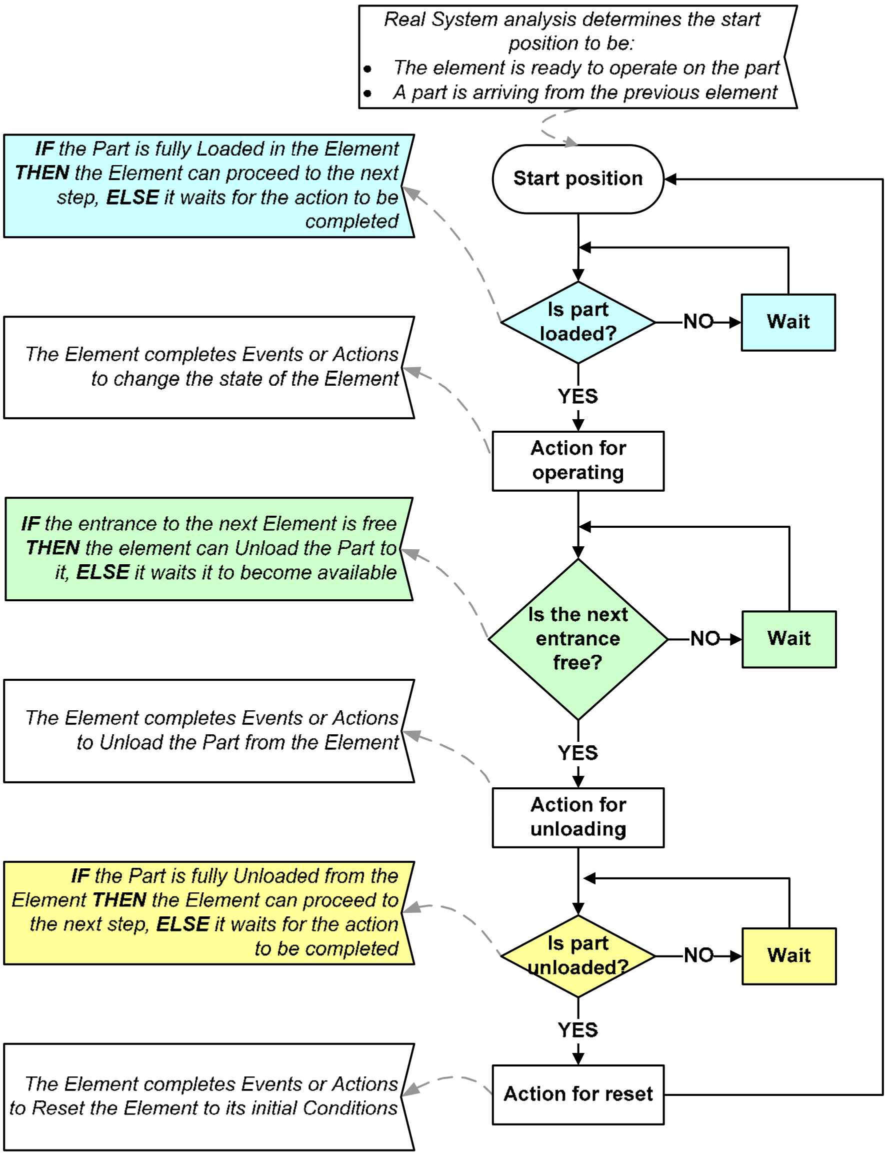


Figure 5-12: General Logic Flow Representation

To optimise the representation process, a limited number of apparently 'simple' elements were chosen to be diagrammed. The majority of the LAL components have a capacity of one part or platen. The more complex elements follow the structure with more scenario possibilities. After identifying common logic patterns for the simple elements the proposition can be made that the 'complex' elements lend themselves to the approach followed.

5.5.3 Stop Module

The search for a common approach to representing the elements of the LAL enables the diagramming to be simplified. Transferring this approach into the diagrams enables the common Stop component to be isolated. The Stop allows element interaction through Part flow. Figure 5-13 shows how this stop component of an element appears to work when permitting a Part to leave an element.

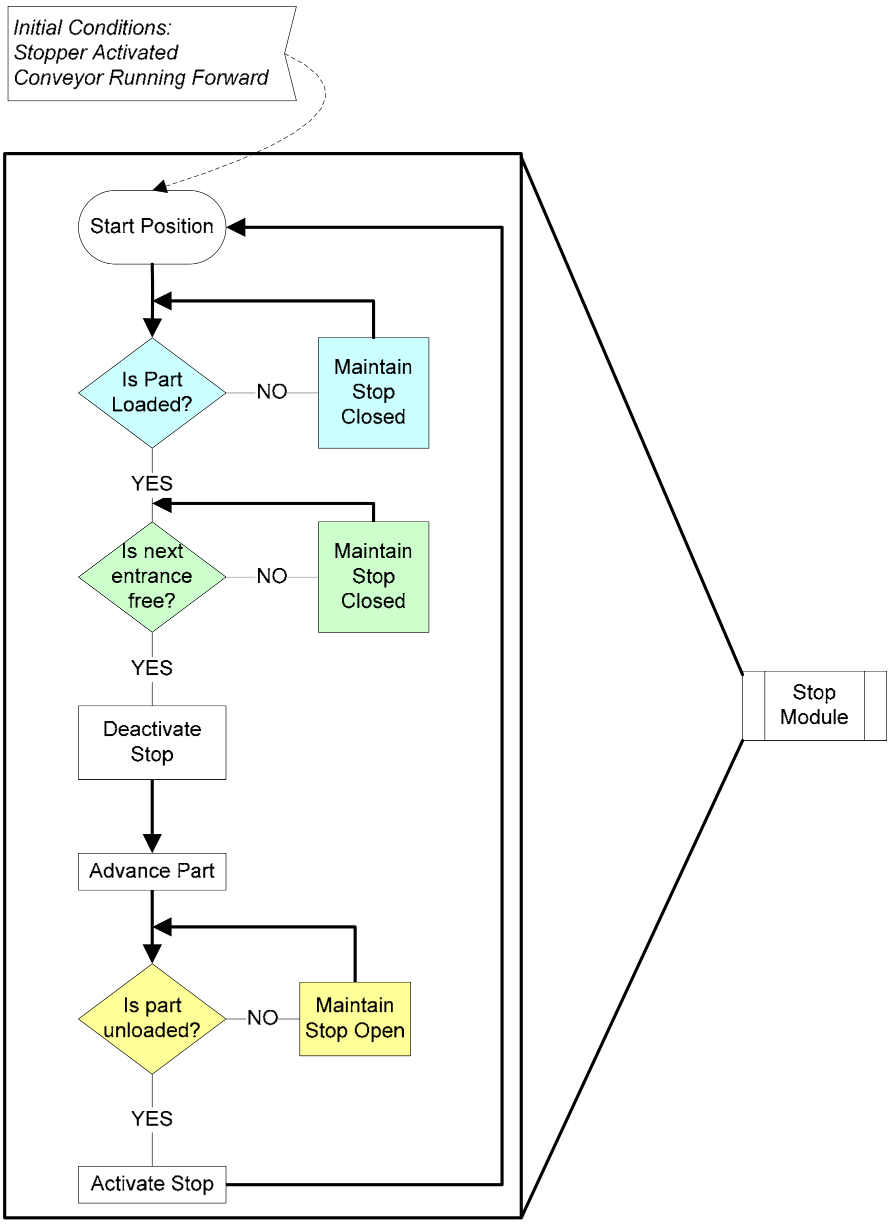


Figure 5-13: Element Common Stop Module

The logic pattern shown in Figure 5-13 appears to apply to many of the elements. The "Stop Module" aims to provide a simplified approach to diagramming the final stage of the element logic flow when releasing a part. An example representation of an Elevator can be seen in Figure 5-14 containing the flow pattern from Figure 5-12 and the stop module from Figure 5-13.

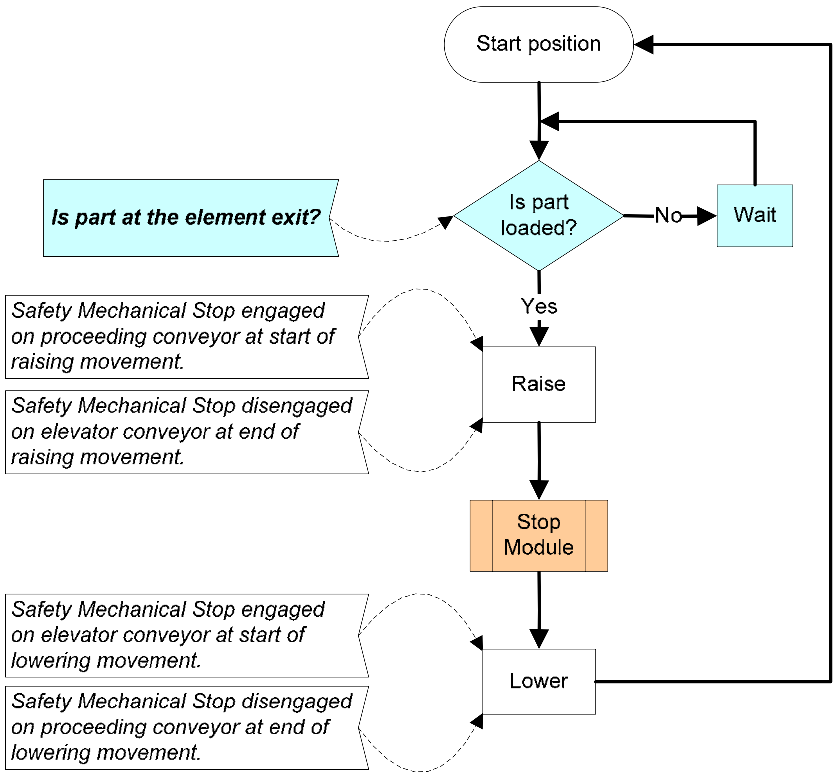


Figure 5-14: Flow Representation of Elevator Using Stop Module

This approach however made some of the diagrams more complex as the module is standardised and modifying it for specific element would render the approach inaccurate. When attempts were made to represent some scenarios with the stopper module it became complex and hence lost the communication benefits of the flow representation.

5.5.4 Scenarios Representations

Element analysis is based on breaking down observation scenarios. Some element scenarios are relatively fixed and others vary. The Divert is an example where the scenario complexity at this stage of the research was difficult to represent. The Divert injects or ejects parts to or from the main assembly line due to quality defects. A scenario exists where a Divert is located after a Test operation. In an attempt to represent this scenario it was discovered that there must be communication with the control system to inform the actuators on the Divert in which direction to rotate to accept a part. The complexity can be seen in Figure 5-15. This scenario is described in Appendix E.

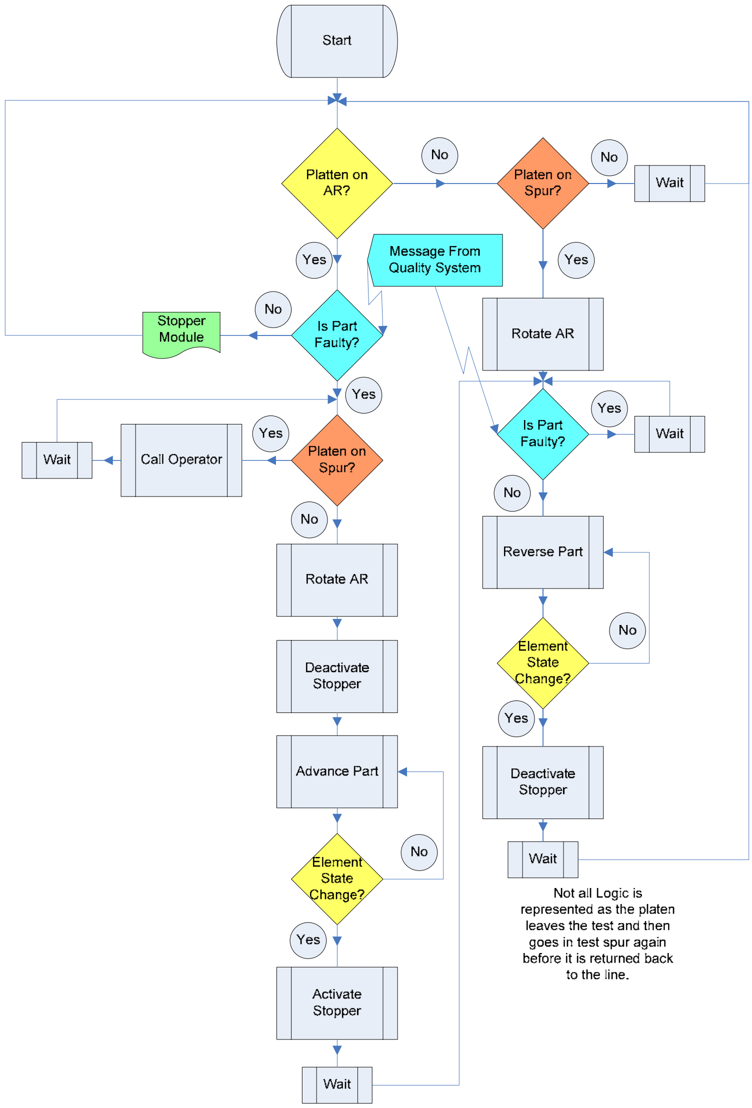


Figure 5-15: Flow Representation of Divert Using Stop Module

The communication strength of the flow diagram is lost when they are used to represent complex scenarios. It can be seen that during the representation of this scenario the pattern of logic decision points and processes does not stay close to the pattern discussed earlier. The approach is then taken to attempt to make the language more common between elements.

The system is built of elements attached together physically, electrically and logically. This interaction between the elements must be represented logically in order to allow a picture of the complete system to be built up. Evidence from Figure 5-15 shows that the diagrams are required to be more simply and interactions shown more clearly.

5.5.5 *Element Interactions*

Modelling the interactions between elements proved difficult without representing communication signals from other sources or elements. These signals can be hardwired direct signals from a sensor to an actuator. The signals may also come from the control system, quality system or mechanical links between elements. Without the representation of the transfer of information between elements the interactions cannot be modelled. With this in mind the Elevator Logic flow diagram can be improved as shown in Figure 5-16.

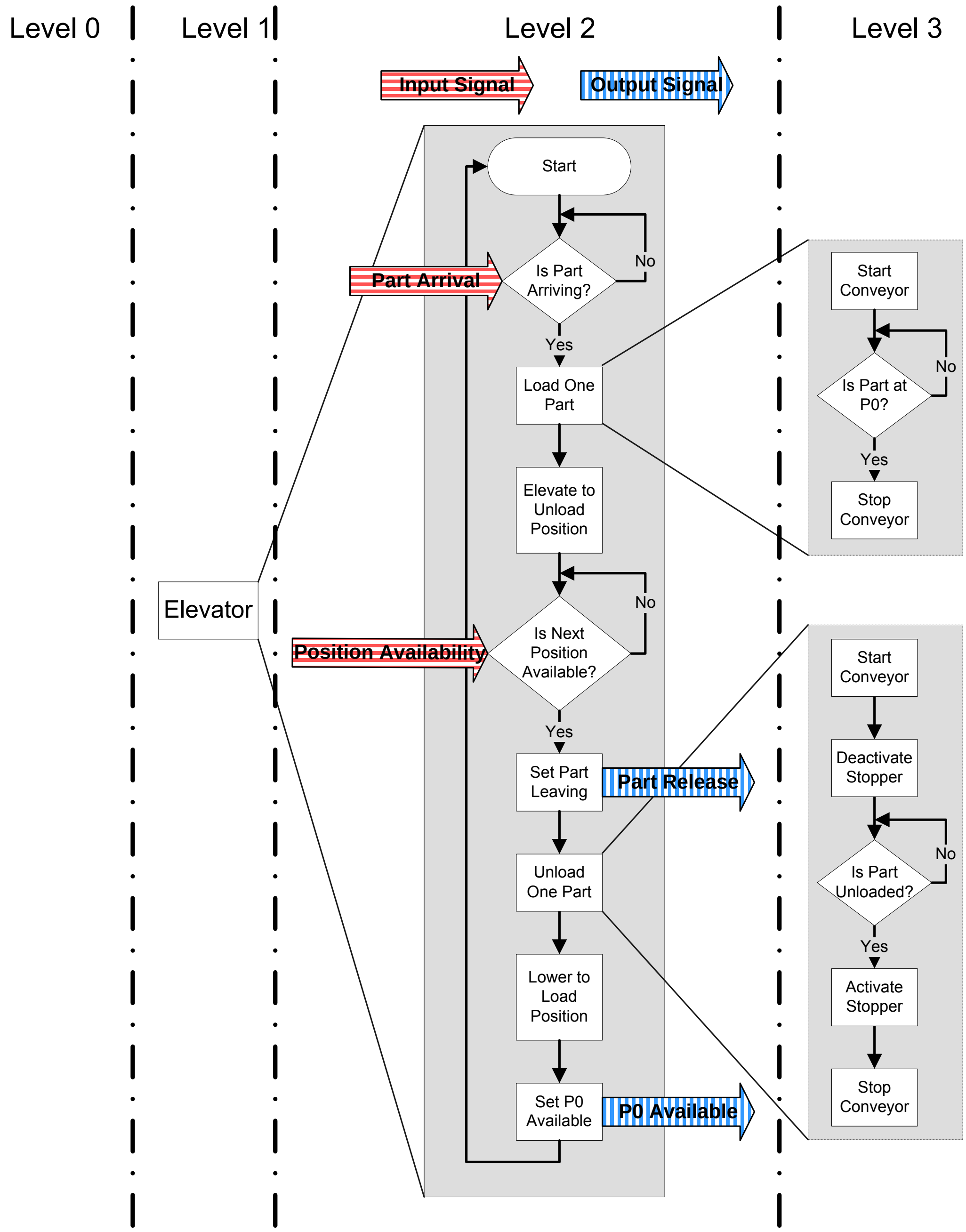


Figure 5-16: Improved Representation of Elevator Logic

As can be seen the initial conditions have also been modified to account for the fact that there is a loading action required by the Element. P0 in Figure 5-16 refers to the Platen position over the Element Stop. Through iterations and increased knowledge of the assembly line the common flow of logic introduced earlier and the vocabulary used has been modified. There are key processes that have also been decomposed in Figure 5-16. This shows that there can be a general overview of the logic level showing what happens within the part flow. Level 3 shows the logic of ‘how’ the key processes at Level 2 occur. The interactions between elements are not through this lower (or deeper) level of logic. The input signals required for element processes to begin are represented entering the element logic at decision points. The output signals that may transpose to other element inputs are depicted exiting the element logic at key processes.

5.6 Chapter Summary

The completion of this stage aimed to provide a firm foundation of understanding of the Lion Assembly Line tin order to inform the preceding validation stage.

Methods employed include observation and depiction of the flow of parts through the LAL. The tools, techniques and elemental approach defined and simplify the analytical approach. The methodology followed allowed the behaviour of the LAL components to be recognised and analysed also facilitating element grouping and definition. Discussion of the complexities involved when analysing and representing the gathered findings, such as logic depth, were presented. The approaches taken to represent the logic in flow diagrams, the associated problems and solutions highlight system analysis difficulties. These difficulties included representing complex logic and Part flow interactions between elements. Solutions to overcome the issues were also mooted.

The LAL can be decomposed into constituent elements by observing their actions in the real system. These interpretations of the elements are subjective and open to interpretations based on the view point of the researcher. The external position of the researcher allows the logic to be genuinely represented without bias. The unbiased and true representations of the assembly line can be verified, validated and aligned with the Ford perspective to ensure comparable evaluation of logic gaps at a later stage.

6 Logic Diagram Verification and Validation

The Verification and Validation (V & V) carried out from three perspectives aims to ensure that all the necessary logic components of the LAL are identified to a sufficient depth, allowing unambiguous communication. The three perspectives are Control System, Simulation and Assembly. Each phase involves reviewing the approach taken ensuring flow diagrams are understandable and have the correct logic content. Section 6.1 presents the V & V methodology with the following three sections presenting the results from participant feedback.

6.1 Verification and Validation Overview

This section lays out the justification, methodology and specific issues of the logic diagram Verification and Validation (V & V) stage.

6.1.1 Necessity of Diagram Verification and Validation

The logic flow diagrams require reviewing and inspecting to ensure that the layout and clarity of the diagrams fulfil their communication requirements. This is completed in the verification phase of the methodology. Validation is required to ensure that the logic has been truly and fully represented to the correct level of detail to represent reality. The V & V gives strengths to the analysis, ensuring the specification produced has the depth and accuracy required by the stakeholders to fully utilise the document.

6.1.2 Generic Verification & Validation Methodology

1. Identify Validating Party	Three V & V perspectives are required from the control system, simulation and LAL. Detailed V & V is required from the participants, thus requiring experts from the particular field.
2. Understand Perspective	Gaining an understanding of the perspective of the V & V party is crucial to focus the approach of the questions and maximise the feedback value.
3. Introduce Analysis	Presenting the approach followed during Stage 1 introduces the researchers' level of understanding to the V & V party.
4. Verify Diagrams	The approach employed and clarity of the representations is verified with the participant.
5. Validate Diagrams	Using the participants' specialist tools the logic content of the diagrams is validated for accuracy from their perspective.

6. Feedback Analysis	The specific issues from the participant feedback are reviewed to determine whether logic diagram modifications are required.
7. Diagram Improvements	Dependant on the requirements from the feedback analysis, improvements are made to the representations of reality.

6.1.3 V & V Considerations

This section introduces a selection of considerations that were taken into account.

Vocabulary

The diagrams are V & V by people who are familiar the LAL terms and vocabulary. The diagrams must therefore be presented in a manner and language that the V & V party can read and understand. The language must be unambiguous with limited jargon, so opening the diagrams to all participants. The language and terms employed are therefore validated with the participants.

Interactions

During Stage 1, the complexity of representing the interactions between elements became apparent. Queries are aimed at three perspectives to extrapolate information and gain a greater understanding of the system allowing interaction documentation.

Represented Logic Level

Each participant is asked about the level of logic, gaining consensus from all participants that the logic depth reached is to the right level and accurately representing reality.

Iteration Possibilities

The participant feedback may require the completion of iterations of real system analysis. This is the case if new elements, scenarios or situations result from the meeting. These are investigated on the LAL for the complicity of the logic inclusion in the ALS. This re-validation of additional information gives strength to the work.

6.2 Controls Perspective

This section presents controls perspective review of the logic flow diagrams. The structure of this section follows the generic methodology introduced, the results are summarised in Table 6-5 followed by a review of the key points. Finally changes to the logic diagrams are discussed.

6.2.1 V & V Party Identification

Industrial Controls Training and Consultancy Specialist

Logic flow diagram examination is required from the controls perspective to give a complete understanding of the LAL beyond information obtained by observing the real system in Section 5.1. The controls participant is the training and development specialist. They compiled a Specification Document of the control system for use by their suppliers. A controls perspective enables the researcher to go down to a high level of detail; the control signal interaction between sensors, control system and actuators. This knowledge enables the researcher to move up through the logic to find an appropriate level of accuracy to represent the LAL logic applied the simulation model. An overview of the control system is given in Appendix C

V & V Tools

The V & V was carried using the diagrams, printed control system specifications and a control system programming software package.

6.2.2 V & V Feedback

The review of the diagrams is summarised in Table 6-5.

Table 6-5: Logic Diagram Feedback from Controls Perspective

Stage 2 V & V Criteria			Stage 1 Representation Summary	LAL Perspective Feedback
		Verification		
Approach Taken	Analysis Method		LAL split into element components.	Elemental approach novel to participant. Approach is easy to follow.
			Few sensors located on line.	Observation method change required as there are many sensors on the conveyor allow pseudo analogue platen monitoring.
	Element Boundaries		Boundaries defined by observing cycles based on part flow.	Element and element boundary concepts not used in control system definition.
Flow Diagram Clarity	Symbols		Standard Flow chart terminology and shapes.	No issues with symbols. No explanation required with Standard approach .
	Vocabulary		Mostly Ford Terminology Used.	No issues with vocabulary. Lack of jargon aids understanding.
	Message		Initial conditions of element generically stated.	Set specific initial conditions of the elements with each diagram clearly.
		Logic		
Logic	Element	Automation Components	Conveyor communicates with other elements that a Part is leaving.	Generally other elements wait for a part to go over an activating sensor when it arrives at a specific position within the element.
	Interactions	Operation	Operation interacts with immediate element neighbours.	Specific communication of a part arrival can be received by an operation several pitches before the part arrives. Message from control system, other element or Antennas.
	Depth	Automation Components	Two levels of logic shown on diagrams.	Both logic levels in diagrams are higher level than used in the control system.
		Level 3	Processes at Logic Level 2 do not take a significant time.	The approach where these processes do not take time is comparable to the controls system processes at a low level.

Important feedback comments from Table 6-5 are analysed in the sub-section 6.2.3.

6.2.3 Feedback Analysis

This sub-section presents criteria from Table 6-5 that are deemed to require further discussion.

Flow Diagram Clarity Verification – Analysis Method

The checking sequence that is used in the controls case can be cross referenced to the methodology used in building the flow diagrams:

Table 6-6: Control System Check vs. Logic Diagram Decision

Controls Logic Checks	Research Flow Diagram
Can process can be carried out?	Is next part arriving?
Is the process being carried out?	Is next position available (after process completed)?
Has the process stopped?	Is part Unloaded?

This comparison is applicable at the high level logic, Level 2 (Figure 5-16). Modifying the approach to the controls logic checks allows further logic depth to be acquired if necessary.

Flow Diagram Clarity Verification – Message

Some element flow diagrams do not clearly take a reader through the processes and decisions. The diagrams require some text leading through the logic flow to minimise interpretation issues.

Element Logic Validation – Automation Components

Conveyor elements are passive as they do not perform any action until a Part has reached the element stop. The flow representation of the conveyor logic is not accurate. This highlights a real system interpretation difference between the controls perspective and the external perspective of the researcher.

Logic Interaction Validation – Operation

The real behaviour of an operation discussed in Table 6-5, highlights the problems associated with identifying a common approach to represent the inter-element communications. This is due to the possibility that the elements have of inter-communication to any point in the line using Antenna and the control system. The antennas on the line therefore play an important role in the element interactions.

Logic Depth Validation – Automation Components

The automation component flow diagrams show similar patterns. The level of logic displayed in the diagrams to the controls specialist is higher than their familiarity. The depth that is possible to go into on the logic flows is great and can be burrowed into deeper by asking more questions in the processes at Level 3,Table 6-6. This allows the logic to be systematically broken down to the lowest level. The lowest level of logic was demonstrated using the example from the control system around an element Stop. The logic structure at this depth is complex with structured text computer language used to program interactions.

Logic Depth Validation – Level 3

At the deep level shown by the controls specialist it is evident that the way in which the control system is built up is of control signals that dictate how and when actions and events occurs. These dictating controls signals do not take a significant time. This is similar for the Level 3 logic of the flow diagrams.

6.2.4 Improvement of Logic Diagrams

There are no direct recommendations to modify the logic representations. However it is recorded that the initial conditions and a textual description of the flow diagrams will increase understanding.

6.3 Simulation Perspective

This section presents the Simulation Specialists review of the logic flow diagrams. The structure of this section is similar to the previous one. Table 6-7 summarises the topics discussed. A discussion of element boundaries is followed by a review of the changes to the logic diagrams.

6.3.1 V & V Party Identification

Simulation Specialist

The review from this simulation perspective aligns the representations of the LAL logic to those within the simulation model. Alignment of the LAL logic representations with the elemental behavioural interpretations in the simulation model ensures an accurate comparison of logic accuracy.

V & V Tools

At this stage the simulation model is introduced in detail to the researcher. The FAST interface and Witness simulation program (Appendix D) are interrogated during the review.

6.3.2 V & V Feedback

The review of the diagrams is summarised in Table 6-7.

Table 6-7: Logic Diagram Feedback from Simulation Perspective

Stage 2 V & V Criteria			Stage 1 Representation Summary	LAL Perspective Feedback
Verification				
Approach Taken	Analysis Method		The logic for the main line and all sub lines was analysed for patterns.	The simulation does not model all the sub-lines.
	Element Boundaries		Elements defined by repeatable piece of equipment with an element stop.	Elements defined by repeatable piece of equipment with Pre-stop, operation of piece of automation and a buffer.
Flow Diagram Clarity	Symbols		Standard Flow chart terminology and shapes.	Colour coding advised to aid understanding and communication of patterns of logic between elements.
	Vocabulary		Mostly Ford Terminology Used.	More specific LAL and simulation terms introduced.
Validation				
Logic	Element	Operation	Operation waits for part to arrive from previous element.	Operations PULL part from element Pre-Stop.
	Interactions	Elemental	Interactions through input signals.	Complexity not required due to element boundary modification.
		Ancillary Logic	Ancillary logic not covered in Real system analysis.	Ancillary logic can effect the behaviour of an element in the system.
		Level 3	Breaking down logic to level 2 allows sub families of elements to be represented.	Level 2 not required as sub families are not required to be differentiated for modelling purposes.

Important feedback comments from the Table 6-7 are analysed in the sub-section 6.3.3.

6.3.3 Feedback Analysis

<u>Flow Diagram Clarity Verification – Analysis Method</u>

It is possible to model all the sub-lines of the real system shown in Figure 5-7, however this is not necessary. The boundaries of the simulation are set to include activities that affect the simulation outputs (Appendix D) or productivity statistics, such as JPH, buffer size, CTs and breakdowns. Manual operations do not have associated break downs as the operators are assumed to complete their work content for a full shift. Also breakdown occurrences of automation equipment are rare in the LAL as they have long Mean Time Between Failure (MTBF) figures exceeding much of the other breakdown times. The repair time for a piece of automation component is also short as spares are available quickly. Using these assumptions the boundaries of the simulation model can be reduced not to include sub-lines such as the kitting area which is built up of only automation components and manual operations. The kitting area also has a large buffer that can supply the line for the completion of the average repair period of the automation equipment. On average, kitting area breakdowns have insignificant affect on the main line.

Flow Diagram Clarity Verification – Element Boundaries

All elements are aimed to be based upon a simple operation with a Pre-stop, operation with data distributions and an output buffer, as shown in Figure 6-17:

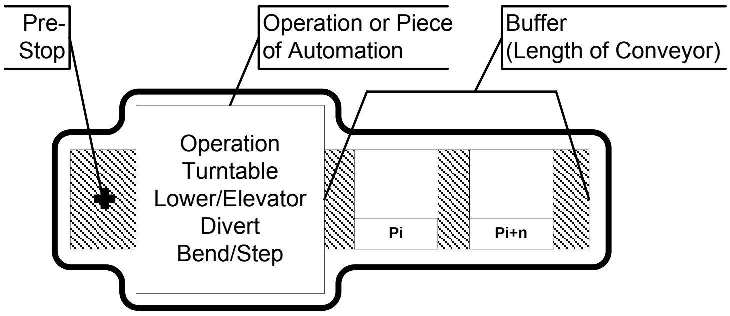


Figure 6-17: Generic Element Boundary Representation of an Element

Figure 6-17 shows the simulated element boundaries. This representation of the boundaries can be seen to reduce the number of elements of the scenario in Figure 5-9 and is demonstrated in Figure 6-18:

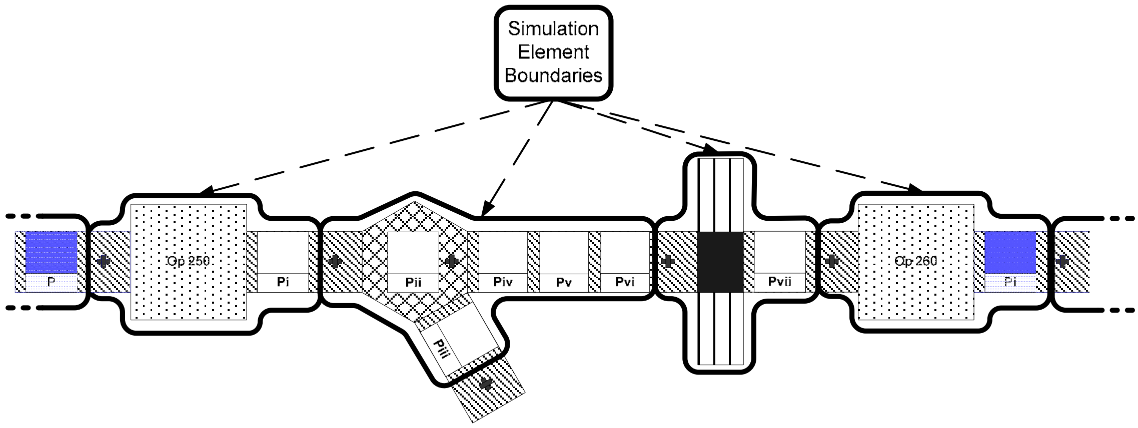


Figure 6-18: Simulation Element Boundaries Applied to Example Section

Representing the logic of an element in this manner simplifies the simulation modelling process. This can be shown by comparing Figure 5-9 and Figure 6-18. There are less elements, boundaries and therefore interactions making the simulation model less complex to construct. However these boundaries are less intuitive. This is the interpretation that the systems analyst (Simulation Specialist) has used, it is up to the researcher to prove, or otherwise, that this way of representing the logic is adequate. These logic boundaries were first devised in 1982. The theory behind defining these boundaries has remained constant since this time.

Logic Interaction Validation – Elemental

The majority of the input rules from one element to the next are PULL rules within the Witness simulation code. The number of observable element interactions has reduced as a result of the element viewpoint modification. The methodology to build the complex logic interactions was through Input and Output signals into decision points and out of processes. With the new element boundaries the inter-element interactions are fewer and do not require the same complex logic representations. The exchange of communication signals between the elements is not required as the interaction between the elements in the model is solely with Part flow. The exchange of Parts occurs if both elements are in the correct state to accept a part. With the new boundaries the majority of interactions are internal between the stop before the element (the Pre-stop), the operation or piece of automation and the output Buffer. These internal interactions are not required to be represented within the logic flow diagrams as they do not effect the modelling of a complete system. The central process in an element pulls from the Pre-stop and pushes to the buffer conveyor when the cycle is complete.

Logic Interaction Validation – Ancillary Logic

The model contains some external system logic; know as ancillary logic, which is used to model the LAL to the required level of accuracy. The ancillary logic allows external activities to interact with the simulated LAL. The ancillary logic can be included in the FAST interface as a Frequency Event (Appendix B). The periodic interaction of material delivery trolleys with the behaviour of an element is an example of a frequency interaction. The ancillary logic is reviewed with the real system to validate the logic and whether it is still true. The ancillary logic may prove hard to represent in flow diagrams as there are many complex interactions, such as in the Zones (Appendix E). Other examples of Ancillary logic are listed below and described in Appendix E:

- Auto-Test Failure
- Frequency Events
- Line Transfers (Sub to Main)
- Marriage Points
- Part Quality ejection/injection
- Special Operation Interaction
- V6 – V8 Derivative Changes
- Zone interactions (Automation Breakdown)

Logic Depth Validation – Level 3

Within the logic of Witness how something occurs is not included, this level of detailed is not necessary in Witness to model the system. The depth of logic analysis presented is too deep when considering Level 3 logic level. The logic in Level 2 is also too deep however the actions documented can easily be matched to real life. The actions that are modelled in Witness take a time, such as the time for Elevator to raise a part. The components of the diagrams that take a significant time are modelled processes, minor time period processes are included in this. The decision diamonds represent the logic that causes the events to occur.

6.3.4 *Improvement of Logic Diagrams*

The diagrams can be simplified by removing the Level 3 logic structure as this is not necessary for simulation purposes. The processes that do not take a significant time are moved from the flow diagrams. The recommendation of adding a colour code to the diagrams is validated by the simulation expert, confirming that it would help to convey the patterns in the logic between the elements.

Element boundary modifications simplify the hierarchy of elements, reducing the number of them. The modified hierarchy of the elements is shown in Figure 6-19.

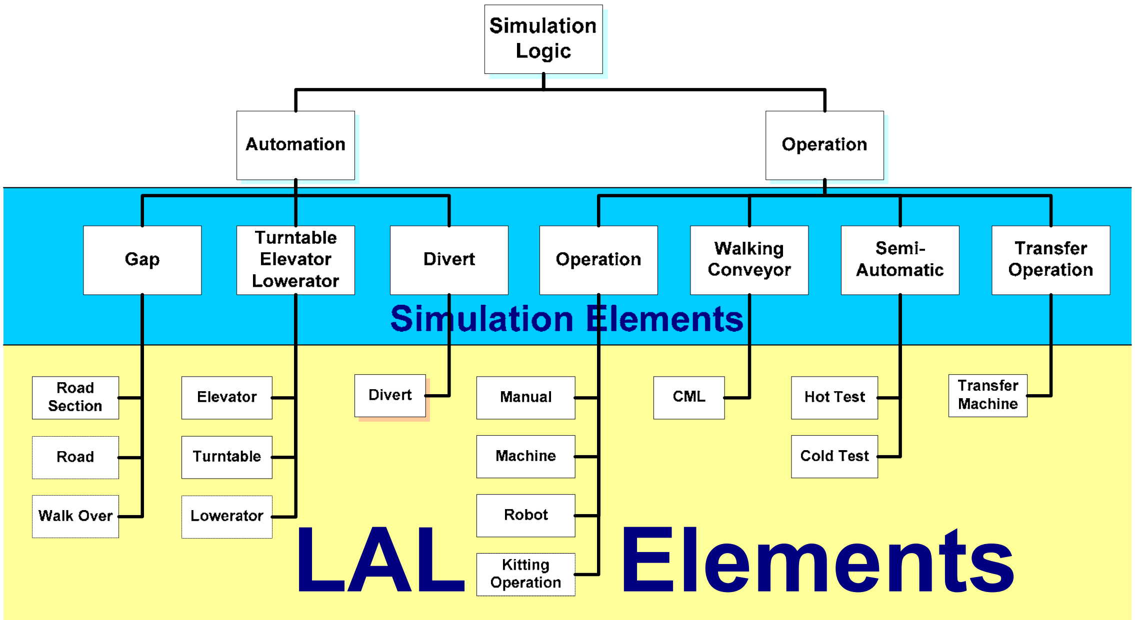


Figure 6-19: Updated Element Hierarchy

The updated hierarchy combines the simulation elements resulting from the V & V phase and the identified components of the line. The new hierarchy of elements is now less complex and easier to view; moreover none of the detail has been removed as it is combined into the remaining elements. The ford vocabulary is also refined in Figure 6-19.

6.4 Lion Assembly Line Perspective

In this section the LAL perspective is applied to the diagram V & V stage. The structure of this section is similar to the previous sections 0 and 6.3 and Table 6-8 summarises the topics discussed.

6.4.1 V & V Party Identification

LAL Specialist

V & V of the flow diagrams with a LAL view allows the comparison of the simulation requirements with those in real life to ensure complicity of the modelled components.

V & V Tools

The V & V is carried out using the intricate knowledge of the LAL Specialist and the holistic understanding of the researcher. The responses on criteria such as ancillary logic are valuable as they are not easily observable in the real system. Interactions with the quality system computers on the LAL are required for some feedback criteria.

6.4.2 V & V Feedback

The review of the diagrams is summarised in

Table 6-8.

Table 6-8: Logic Diagram Feedback from LAL Perspective

Stage 2 V & V Criteria			Stage 1 Representation Summary	LAL Perspective Feedback
Verification				
Approach Taken	Analysis Method		Logic identified by observing the system.	Logic approach to looking at the LAL is a new approach to the validating party.
	Element Boundaries		Elements defined by repeatable piece of equipment with an element stop.	The elements identified agree with the LAL perspective.
Flow Diagram Clarity	Symbols		Standard Flow chart terminology and shapes.	Diagrams appear simple, straight forward and clear with notation used.
	Vocabulary		Mostly Ford terminology used	Terms are non-ambiguous
	Message		Initial conditions of element generically stated.	Initial condition importance highlighted.
Validation				
Logic	Interactions	Ancillary Logic	No interactions or Ancillary Logic Represented.	High level logic has interactions with many other elements and logic in ancillary scenarios.
	Depth	General Observation	Logic represented at two levels showing interactions.	Despite the novelty of the approach for the participant, the depth appeared to represent what happened in the LAL.

Important feedback comments from the table above are analysed in the following sub-section.

6.4.3 Feedback Analysis

Logic Interaction Validation – Ancillary Logic

Ancillary logic discussions were the strength of the meetings' feedback as the ancillary logic is difficult to observe. Through ancillary logic discussions, it is recognised that a high level of logic has many interactions with the potential to be complex. An example of the complex interactions is from poor quality parts. Poor quality parts can be due to problematic assembly components causing an operation to have an error. This affects the cycle time of the particular operation and following operations until it is ejected from the main line, thus changing the Part flow. Repair operations are performed off-line, the Part is injected back into the line at a number of places depending on the nature of the problem. This process affects many elements within the LAL with complex logic interactions. The process of the Poor Quality issues is included in the Assembly Line Specification in Appendix E (Part Quality Related Extractions and Insertions).

6.4.4 Improvement of Logic Diagrams

The perspective of the real system gave the view that the logic flow as it stands is a good representation of what happens in the LAL. However, it is apparent that this level of analysis is not considered for the day-to-day operation of the LAL. The management of the system does not require this knowledge in order to maintain the part flow through the LAL. The inclusion of this information in the document can be used by the simulation expert to make judgements about whether the inclusion will be beneficial to the model and its productivity outputs. The logic diagrams do not require modifications based on the LAL specialists feedback.

6.5 Chapter Summary

This stage was carried out to ensure that the real system analysis results were represented accurately, with enough scope and logic depth. The V & V used three perspectives from specialists of the Control system, Simulation and LAL. The approach taken and logic flow diagrams were introduced to the participants.

The control system perspective gives a method variation if deeper logic analysis and representation is required in future stages. The simulation perspective feedback provides a significant change to the methodology of defining element boundaries. The new methodology reduces the number of elements and also interactions, simplifying the real system analysis and modelling requirements. The validation provided directions of possible ancillary logic requiring further LAL analysis. The assembly perspective expressed the novelty of the approach to their view of the LAL. Details and behaviour of the ancillary components were received. Confirmation was given that all logic components that affect the assembly line were recorded.

With the Verified and Validated information and logic representations the ALS can be researched and developed.

7 Assembly Line Specification Creation

The purpose of this stage is to present the specification creation of the logic mechanisms observed from the Lion Assembly Line (LAL) to enable the gaps and correlations to be identified in Stage 4. A pivotal issue raised during the first step of the methodology is addressed and a solution presented. In the first section, the verified and validated logic from the previous stage is combined with the literature review results and stakeholder requirements. In the second section an issue with the confidence in the model and specification of the LAL is addressed and the ALS is produced. Finally, the assembly line specification is analysed and possible solutions to the issues raised from previous phases are addressed.

7.1 Specification Framework

The aim of this research is to increase the confidence in the simulation models. The ALS has been defined as a tool to do so. The requirements of a specification to completely achieve the aim are discussed in this section. This section summarises the content and structure of a specification to support the achievement of the aim.

7.1.1 ALS Stakeholder Use

The stakeholders of the specification and simulation share commonalities. The stakeholders may use the ALS for the following reasons:

For Reference	● The ALS could be used the stakeholders as reference for a particular simulation project. The identification of the document as a central point of reference for simulation stakeholders appeared in discussions with them and in literature (Carson, 2005).
For Model Maintenance	● The specification has the potential to provide a structure to follow when updating the simulation (Gass, 1984).
For a Simulation Specialist	● To gain a greater insight into the real system. ● To build more accurate simulation models.
For a Simulation Novice	● To quickly increase knowledge of the assembly line and its modelling requirements. ● To understand the element boundary methodology. ● To understand how to define elements and the logic of new elements as necessary.
For Productivity and Process Engineering	● To understand how the simulation represents reality. ● Increase belief in model outputs for process modifications. ● To verify the simulation model behaves as reality.

7.1.2 Stakeholder Requirements

The stakeholders' requirements of the specification must be understood. During open meetings with various Ford employees in the above areas, questions such as those included in the list below were asked:

- What do you use the simulation outputs for?
- Do you trust the outputs
- How would the information be best represented?
- How will the information be used?
- If so, why?
- If not, why?
- If not, what would you like to trust it?
- What information would you like to be contained in the document in order to understand the real system and the simulation?
- What would you use it for?
- Why do you need to trust it?

The main stakeholder who has the greatest interest in the ALS is the Simulation Specialist. The principle aim of the document is to increase the confidence held in the simulation model by the stakeholders. An example of why the model is not believed comes from Process Engineering who uses the simulation outputs for Buffer (Appendix B) capacity optimisation. Modifying buffer capacity, in some cases, has little or no affect in the model outputs; the belief from experience does not support this. Buffer decisions are a regular use of the simulation model for this stakeholder category. With the ALS the behaviour of the components of the Buffer is specified allowing the validation with the real system and the simulation either proving the simulation correct or identifying changes to make to the model.

7.1.3 ALS Format

A requirement for an ALS is that the information must be quickly and easily obtainable. The focus should be on ease of understanding allowing communication of the content to be conveyed efficiently.

The specification itself may not be trusted by a stakeholder and their own V & V of the document may be required by visiting the Assembly Line. A strong justification of this is when the ALS and simulation is used by another Ford engine assembly facility. The simulation is applied in all the Ford engine manufacturing facilities in the UK. The ALS is developed at the LAL facility in Essex, directly applying the document to other facilities may result in issues associated with lack of ownership. The issues may manifest themselves in reduced confidence in the document itself. The information contained should be focused to their needs and easily printable to allow them to take it to the real system in question for verification and validation. Producing a document with the ability to follow it linearly from a low detail level increasing to high levels of detail is useful for a simulation novice when creating simulation models. The trend for the ALS from the stakeholders is that it should be focused to their individual needs. The ALS must therefore be comprehensive, flexible and simple to satisfy the range of requirements from the stakeholders. The use of the specification by the stakeholders can be correlated to the levels discussed in section 3.3; different stakeholders require documentation for different purposes and the detail involved split into levels.

7.2 Document Framework Development

The ALS development is discussed in this section.

7.2.1 Scope of Specification

The aim of this research is to increase the stakeholder confidence in the existing simulations. Increasing confidence in the model of the stakeholders was believed to be achievable by giving the simulation expert the ability to prove the simulation accuracy with the specification. The requirement for this was to produce an ALS of the element logic. Throughout the completion of Chapters 3, 5 and 6 criteria for a complete Simulation Specification Document (SSD) became apparent. The research carried out on specification document content, to increase confidence in a simulation model, implies greater information requirements than solely logic. The complete SSD in Ford, potentially, can increase confidence in many aspects of the simulation. Ford simulation stakeholders suggest that proving model behaviour using the specification is an important tool for increasing simulation model confidence. It is beyond the scope of this research to produce a complete SSD. However the framework of one is suggested for demonstration purposes. The ALS production aims to increase confidence in the simulation in terms of model behaviour, enabling the achievement of the global research aim.

7.2.2 Assumptions of Assembly Line Specification

An Important component of the ALS is the assumptions made during the system analysis and specification building. The importance of this inclusion surfaced during meetings with the stakeholders. All the assumptions made during the simulation model construction are not included in ALS due to scope restrictions and little knowledge of them. Many of the assumptions included in the simulation were made over 20 years ago and are stored in the mind of the model creator, the Fords Simulation Expert. The general assumptions made during the LAL analysis are included in the ALS and are shown in Table 7-9:

Table 7-9: ALS Assumptions

Assumption 1	A scenario observed more than once on an element or group of Elements occur in normal assembly line operation and can be applied systematically to those Elements thoughout the system.
Assumption 2	Observations of the logic of an element are applied to elements of the same sub-family. Validation of the logic with every element of the same type is not necessary.
Assumption 3	The information given by Ford Employees is correct and represents the real system behaviour.

The availability of all assumptions included in the simulation helps stakeholders grasp justification of simulation behaviour. Research in simulation applications such as Military Combat Simulation (Davis, 1986) identified that detailed knowledge of assumptions are necessary for successful simulation projects.

7.2.3 ALS Inclusions

This sub-section briefs the content of the ALS included in Appendix E.

Definitions

Introducing the terms and definitions used throughout the specification builds understanding of the document from an early point. The definitions include:

- Common Terms
- Elements
- Flow Diagrams
- Sketch Colouring

Methodology

A brief outline of the assembly line analysis methodology and that used to develop the final logic flow diagrams allows the reader to grasp the depth of understanding required to develop the document.

Logic Depth

Justification of the depth of logic represented transmits a shared understanding of the approach of the document.

Element Boundary Modification

An important turning point for the work came about when the boundaries of the elements became simplified using a simulation approach. Introducing the benefits to the reader enables them to tap into the simplicity of the elemental representation.

Sketches

Simple pictorial representations of the elements allow the reader to visualise the Part flow away from the Assembly Line.

Element Logic

Element Logic representations make up the body of the ALS and form the tool for the Simulation Specialist to identify the gaps and close correlations. The logic flows are displayed in a tabular form, allowing textual descriptions to clarify key points.

Ancillary Logic and Special Cases

The real system analysis phase presented special cases of logic and interactions. These are presented in a separate section with ancillary logic and the results of some specific request from the simulation analyst for clarification of unknown interaction scenarios between groups of elements.

ALS Conclusion

A summary of the ALS with specific difficulties encountered and its limitations complete the document.

7.2.4 Assembly Line Specification Production

The ALS can be seen in its entirety in Appendix E, a flavour of the document can be seen in Figure 7-20:

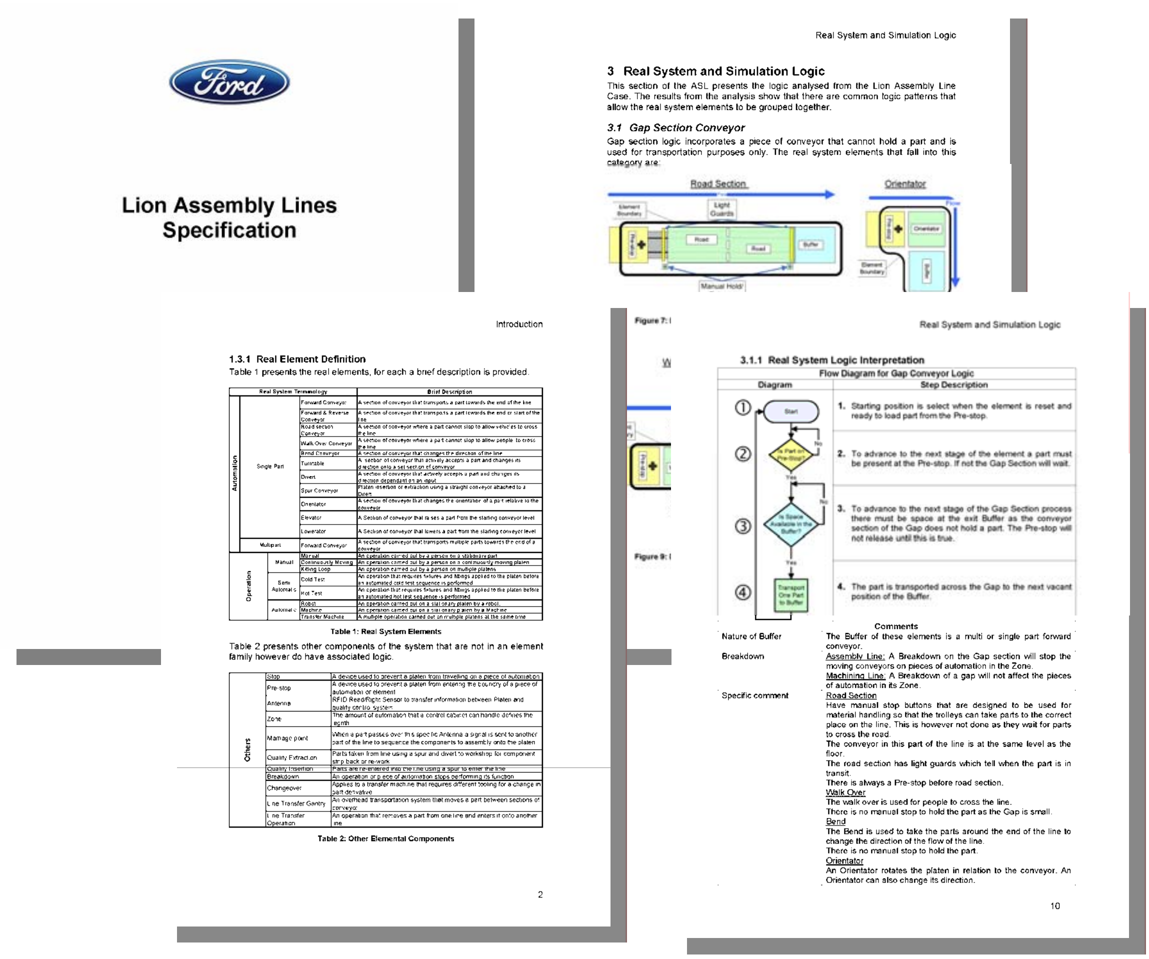


Figure 7-20: Example ALS Document Pages

The example pages of the ALS depict the front cover, element definitions and Gap Section Conveyor diagrams and Logic representations. The ALS conveys the understanding of the Lion Assembly Line gained through the progression of the research and represents the main deliverable to Ford Motor Company. The ALS is in a .doc file, PDF and paper copy. The three formats allow different user access:

Paper	Non Modifiable, Complete Document
PDF	Non Modifiable, Selective Printing
.doc	Modifiable, Selective printing

The three access levels give the Simulation Specialist control over the content of the ALS for specific stakeholders.

7.3 Analysis of Specifications

This Section presents an analysis of the ALS produced. An issue from this phase of the research is identified and a possible solution presented.

7.3.1 Analysis of Assembly Line Specification

The SWOT analysis in Table 7-10 can aid in assuring that the possible content of a complete SSD retain the strengths and continue to provide the opportunities.

Table 7-10: SWOT Analysis of ALS

Strengths	Weaknesses
Accurately represents the real system.	Long document.
Gives a good overview of methodology.	A lot of words.
Stakeholders happy with depth and breadth.	Large file size.
Standard Flow charting approach.	Difficult to navigate through as it is linear.
Colour coding increases communicative power.	Diagrams have to fit to page boundaries makes the text small.
	Special cases are textual.
Opportunities	**Threats**
Opens up simulation.	If the real system is updated ALS may not be.
Communicates exactly what happens on the assembly line.	Adding a new element makes document out of date.
Introduces a written approach to systems analysis.	Document is focused towards simulation specialist reducing value for other stakeholders.
Standard flow diagrams and vocabulary ease communication and increase value of document.	Ford did not directly develop hence there is a lack of ownership of the ALS and so may become obsolete quickly.

The weaknesses and threats identified focus particularly on the ease of use of the document. The ease of use of the document appears to be inversely proportional to the simplicity of compilation. The ALS in its current state is straight forward to produce due to its linearity. Producing a solution to the identified issue may present development complications that require Ford to innovate the solution.

7.3.2 Assembly Line Specification Comparison with SSD

The content requirement of a specification comes from many sources. Section 3.3 shows the investigation of the requirements of the content of an ALS from a research perspective. Interpretation of previous Ford Simulation Specifications (Industrial Engineering E & F Ops Group Staff, 1983) give a flavour of what has been included in past specifications. Review of a more up-to-date control system specification gives a look at the requirements of a specification from that angle.

Comparison of the Ford needs and the requirements recognised in the literature identifies that the Ford requirements are less detailed than the literature. This deviation from the literature could be due to the breadth of applications and country requirements researched. The literature identified as important sources do not cover automotive simulation, particularly when considering the FAST interface with the Witness package. An important difference between the literature suggestions and stakeholder requirements is considered to be the inclusion of assumptions of the simulation and SSD at a higher level. Stakeholders are keen to understand the assumptions at an early stage of simulation learning. The knowledge of these assumptions quickly builds model trust from a common understanding of the assembly line interpretations. A comparison between the potential SSD and the Created ALS is shown in Table 7-11.

Table 7-11: SSD Comparison with ALS

Possible Ford SSD Content		**ALS Content**
Chapter 1	**Introduction**	**Chapter 1**
	Specification Document Use	
	Aim of SSD	Aim of ALS
	Potential Target Users of SSD	
	Terminology of SSD	Terminology of ALS
	Assumptions of SSD	
	Guidance for SSD Use	
Chapter 2	**Simulation Process Overview**	**Chapter 2**
	Purpose of Model	Focus of Simulation
	Scope of Model	Approach Taken in Analysis
Level 0	Overview of FAST Inputs	
	Outputs of Simulation	
	Assumptions of Simulation	Assumptions of ALS
Chapter 3	**Simulation Functional Content**	
	FAST Data and Validation	
	Data Requirements of FAST	
Level 1	Model Validation Procedures	
	Location of Data	
	Data Collection Methods	
	Data Validation Procedures	
Chapter 4	**Real and Simulated System Detail**	
	Simulation Mechanism Detail	
	Detailed Assumptions	
	Simulation Components	
Level 2	**Real System Information**	
	Assembly Line Overview	**Chapter 3**
	Element Boundary Justification	Element Boundary Justification
	Element Definitions	Element Definitions
Chapter 5	**Elemental Logic Definitions**	
	Logic Flow Diagrams of Elements	Logic Flow Diagrams of Elements
Level 3		**Chapter 4**
	Special Case Logic	Special Case Logic
		Chapter 5
		Conclusions

Comparison of a potential SSD with the completed ALS in Table 7-11 shows the gaps in the ALS. The SWOT analysis in Table 7-10 presents areas for improvement to the framework of the ALS that could be incorporated into a SSD. The evidence that the ALS is focused towards the simulation stakeholders' requirements is apparent from the lack of simulation content in the specification. The simulation expert is aware of the simulation and its assumptions, requiring only a real system and logic inclusion in the ALS. Introductory and analytical information provides complicity and addresses document communication issues raised during the research. The inclusion of these areas aims to prevent future misunderstanding of the document. The inclusion of the document creation methodology encourages document maintenance.

7.3.3 Potential SSD Framework

The framework of a SSD refers to the structure supporting the contents of the document. SWOT analysis of the ALS in Table 7-10 provides guidance to the requirements of the possible framework of the complete SSD. Utilisation of the full capabilities of the SSD within Ford requires ownership by the simulation stakeholders. In house Ford consultation of their exact requirements may ensure this.

Framework Requirements

Different stakeholders require various routes through information in the document; some may require a linear, guided approach and others only focused details. The ALS is a '.doc' framework using descriptive text, sketches, introductions to the elements and tables containing Microsoft Visio flow diagrams. The document is large due to the information contained in it, the gaps in the document, identified in Table 7-11, indicate that a full potential document could be even larger. The SSD could be more beneficial to be available in a 'soft' framework. The potential requirements of the framework solution can be:

- Brief
- Focused
- Linear
- Non-linear
- Printable
- Required to give user different access levels
- To allow a stakeholder to use it electronically
- To allow the document to be viewed electronically
- To enable stakeholder manipulation
- Used to validate the simulation model

Framework Formats

During the preliminary research completed identification of some possible frameworks were identified. The framework format suggestions come from different sources including Software Specifications using Unified Modelling Language diagrams (Oscarsson and Moris, 2002). No direct potential framework standards exist to present SSDs in a soft framework, highlighting that Ford should lead the development of a specific framework to match their requirements. Prior knowledge of various documents and web based systems allow conceptualisation of a possible framework to illustrate the benefits of a possible solution. Tools that could be incorporated into the framework may use a HTML interface with links to specific information. The specification pages may be available in PDF format to allow focused documents to be easily printable. Soft frameworks provide an advantageous solution to displaying images and videos to illustrate and explain key points and concepts. Soft versions of the SSD could allow an 'Administrator' to set passwords and access levels to the document, preventing unauthorised modification of the critical areas. Soft versions of the document could allow possible integration into other existing systems such as the controls software used for diagram validation in Section 6.2.

7.3.4 SSD Framework Example

The possible content, stakeholder requirements and format is combined for the framework of the potential SSD. Figure 7-21 depicts an example of such a framework. The centre of the framework is a Specification Data Base with different access levels protected by a firewall. The firewall allows users, or stakeholders, of various access authorisations levels to call and edit information within the data base. The database navigation presented communicates required information through hyperlinked text allowing a user to go through the document as they require calling up only relevant data. The rich picture in Figure 7-21 is a brief representation of one possible solution.

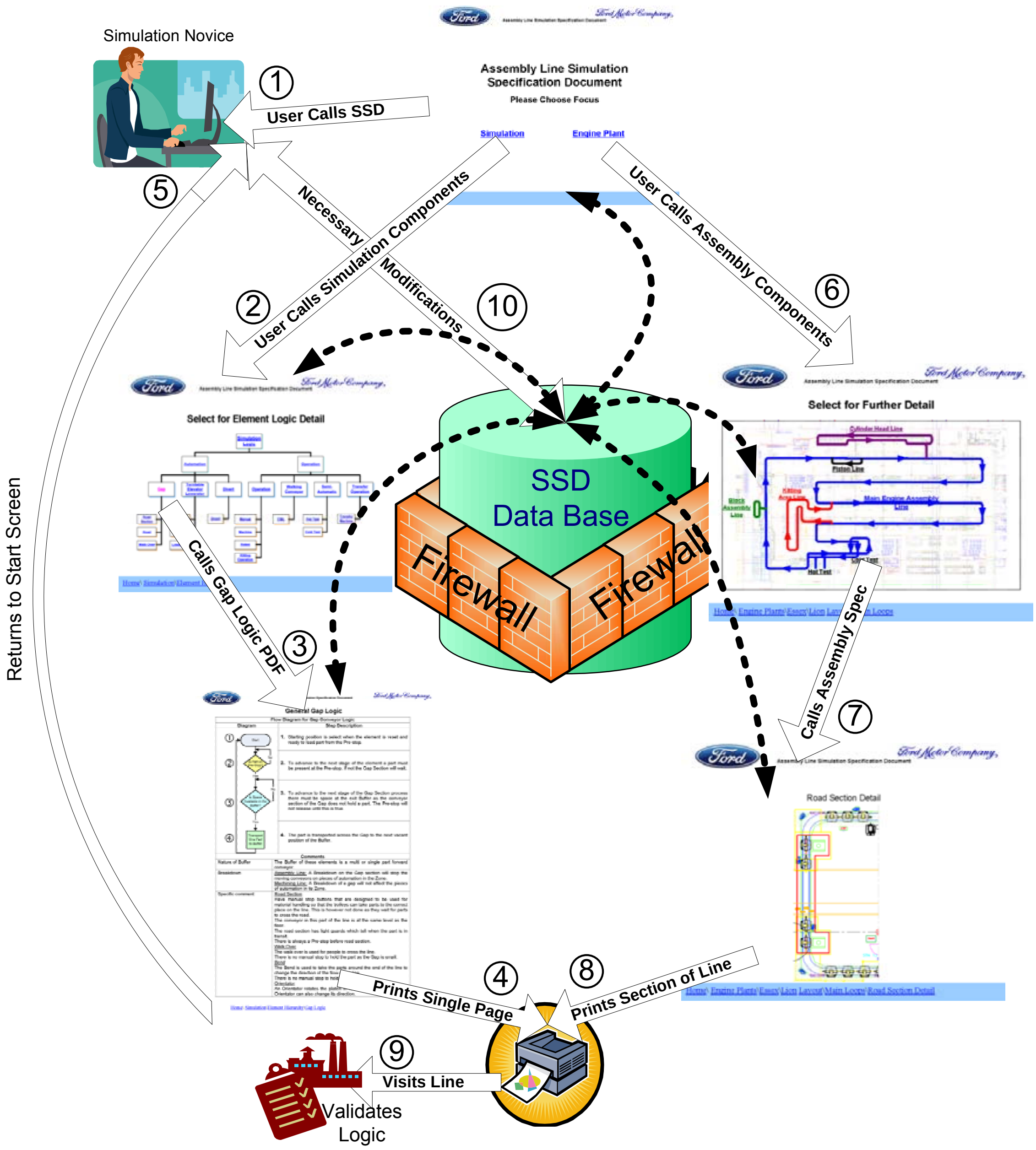


Figure 7-21: Example SSD Framework

Figure 7-21 represents a possible use of a SSD with a web-based framework. The initiating requirement of the depicted scenario is to validate the logic content of the simulation for a Road Section Element (Gap, Appendix E) of a Ford Engine Assembly Line. The steps required follow:

1. A simulation novice (user and stakeholder) logs onto the web interface using any desktop computer with Internet Explorer (or equivalent). The users' access level authorisation is communicated to the firewall on login.

2. The user calls the simulation element list with a hyperlink to the problem element.

3. The user calls a PDF document of the real life logic flow diagram and description (ALS Content).

4. The logic flow is printed remotely to a network printer for easy handling.

5. The user requires the section printout of the assembly line to annotate for later analysis. This is eased by a jump back to the main menu.

6. The user calls the specific full assembly line layout of the facility from a global database of engine plants.

7. The specific location of the element under scrutiny is selected.

8. The specific element layout is printed on the networked printer.

9. Hard copies of the logic flow and real element can be taken to the line for observation, verification and validation.

10. Depending on the users' access level, any modifications based on validation can be made to update the database.

It is beyond the scope of this research to carry out this road of SSD development further. The example in Figure 7-21 aims to give a flavour of the potential of a SSD.

7.4 Chapter Summary

The aim of this chapter was to produce an Assembly Line Specification. Research and stakeholder requests required an inclusion to the methodology, enabling the identification of a document that could potentially instate confidence in the simulation. The modified methodology allowed the purpose of the stage to be more closely met and provides a sounder base to compare the simulation strategies within Ford in the next stage. The ALS produced is an accurate, verified and valid representation of the assembly line, which is unambiguous and will allow the gaps and correlations to be identified in the next stage.

8 Assembly Line Specification Utilisation

The ALS produced and the SSD proposed in Stage 3 support the analytical process in this chapter. The ALS is used to identify disparity between the simulation model logic and the Lion Assembly Line logic in the first section. Secondly, the existing simulation strategy is presented and analysed. Finally, potential improvements to the simulation strategy within Ford using a complete Simulation Specification Document are critiqued.

8.1 Reality and Simulation Comparison

This section presents the methodology employed to identify gaps and correlations between the simulation logic and LAL behaviour. An overview of the results is presented with two specific findings exemplified.

8.1.1 Utilisation Methodology

Comparison Parties

The comparison of the simulation model with reality requires the simulation expert and researcher. The simulation knowledge is mainly stored within the head of the simulation expert and therefore may not be possible for a non-expert to identify disparities between reality and the simulation. The benefit of collaborating with the researcher presents itself during the simulation review discussions. The knowledge of the actual LAL gained by the researcher is greater than the simulation experts', as they are not focused on one particular assembly line.

Comparison Tools

FAST, Witness and the ALS are used to identify the logic gaps and correlations. A lack of a gap implies there is a good correlation with reality. The ALS defines exactly how the LAL works in reality, combining this content with specialist simulation knowledge is pivotal for validating the accuracy of the simulation logic. Analysis of the FAST inputs (Appendix D) that defines the logic of the simulated elements aids the identification of gaps. The actual logic code is buried deep inside the Witness model, knowledge of its location is required to prove the simulation model.

Actual Comparison Process

Schedule restrictions imposed on the simulation specialist did not allow a complete collaborative review of the simulation model using the ALS. A benefit of the verification and validation (V & V) Stage [2] of the research provided insight into the mechanisms of FAST and Witness; both are available to the researcher. The simulation perspective V & V (section 6.3) of the logic diagrams involved the researcher grasping an understanding of the simulation mechanisms. During Stage 2 the simulation expert presented the components of FAST. This gained knowledge of the simulation tools presents an opportunity for the researcher to identify ‘potential’ logic gaps. The potential gaps identified are presented in the ALS (appendix E) for future validation by the simulation expert. The alignment of the LAL elements with the simulation elements after Stage 2 ensures that the logic is compared at the same level, with the same Part motion inclusions and using the same term definitions. The alignment of the researchers’ and simulation experts’ conceptual interpretations prevents the identification of false logic gaps.

8.1.2 Gap Measurement

Non-Quantitative Measurement

Quantitative measurement of a logic gap is not possible by recording variations in the output data (such as JPH) of the model. This comes from the observation that the output accuracy depends heavily on the [estimated] input data required to run the model. For example a gap in the logic can not be identified to produce an extra 2 parts per hour. The JPH is however derived from theories on the throughput of the line.

Qualitative Gaps in Part Flow

Qualitative judgments on whether a logic difference may cause a variation in the throughput between the assembly line and the simulation may be made. These conjectures require both a holistic and a detailed knowledge of the assembly line. The simulation expert has a holistic knowledge of the assembly lines and the ALS can bestow unknown logic detail.

Qualitative judgments on the effect of logic inaccuracies are possible when considering real and simulated Part flow. A simulation objective concludes when the flow of the real system is modelled accurately. The LAL flow behaviour described by the ALS contents can be compared to the part flow in the simulation. If a modification to the simulation logic is required (to align the simulated and real flow) based on the ALS information a possible logic gap can be said to exist.

The behaviour of parts through the line in the simulation model relies on the input logic information. The model logic changes how the parts on the line ebb, flow, build queues and starve elements. The logic gaps can affect the operational throughput when focussing on a small number of operations. If these operations are close to the start of the assembly line (real or simulated) the total throughput of the model may not experience any tell tail changes. This is partly due to the length of the line and the inherent inaccuracies caused by the use of random numbers in the simulation smoothing the effects (Lehman, 1977). Element throughput directly affects the ebbing and flow of the parts and increases storage, or WIP, in the model. Through put variations caused by logic inaccuracies can be identified as gaps.

8.1.3 Results Summary

The results of the gap analysis through researches analysis of the Witness Logic and FAST using the validation process are summarised in Table 8-12.

Table 8-12: Summary of ALS Utilisation

<table>
<tr><th colspan="2"></th><th colspan="7">Simulation Elements</th></tr>
<tr><th colspan="2"></th><th>Gap</th><th>Turntable Elevator Lowerator</th><th>Divert</th><th>Operation</th><th>Walking Conveyor</th><th>Semi-Automatic</th><th>Transfer Operation</th></tr>
<tr><th rowspan="16">Real Elements</th><th>Road Section</th><td rowspan="4">Correlation</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><th>Orientator</th><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><th>Road Section</th><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><th>Walk Over</th><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><th>Elevator</th><td></td><td rowspan="3">Correlation</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><th>Turntable</th><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><th>Lowerator</th><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><th>Divert</th><td></td><td></td><td>Check Scenario</td><td></td><td></td><td></td><td></td></tr>
<tr><th>Manual Operation</th><td></td><td></td><td></td><td rowspan="4">FAST Inputs can cause inaccuracies in Witness Logic</td><td></td><td></td><td></td></tr>
<tr><th>Machine Operation</th><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><th>Robot</th><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><th>Kitting Operation</th><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><th>CML</th><td></td><td></td><td></td><td></td><td>Spaces Possible</td><td></td><td></td></tr>
<tr><th>Hot Test</th><td></td><td></td><td></td><td></td><td></td><td rowspan="2">Correlation</td><td></td></tr>
<tr><th>Cold Test</th><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><th>Transfer Machine</th><td></td><td></td><td></td><td></td><td></td><td></td><td>Correlation</td></tr>
</table>

Inclusion of the explanations for the gaps and correlations are included the ALS to allow the deliverable to remain concise. The gap analyses are briefly described after the relevant flow logic in the ALS in Appendix E.

8.1.4 Example Results Analysis

This sub-section discusses two issues associated with identifying potential gaps. The discussion in detail of all the potential gaps is beyond the scope of the research as the simulation specialist performs this task with the ALS.

Data vs. Logic Gap: The Divert Scenario

A potential gap may exist when a specific scenario occurs. The scenario observed is pictorially represented in the ALS in Appendix E. The scenario causes a queue of parts in reality. The LAL queuing behaviour in the simulation model does not accurately represent the formation of this queue. This is due to the modelled interactions between the elements involved, Machine (Test) Operation and a Divert. The simulated scenario does account for all observable movements of the Divert. The model simulates the Divert motions with a cycle time to complete its rotation. If the specific simulated scenario occurs, the cycle time is double to account for increased rotations before the completion of the scenario. This is the length of time from a Part entering the element, its state changed, exits the element and the next Part enters (if a Part is waiting).

The identification of this potential gap highlights the fine line between data integrity and logic omission. The complete scenario is not modelled in the simulation as the numbers of movements that the Divert makes to complete the specific scenario are not modelled. The effect in the model is that the flow is blocked for a shorter period than in the LAL. The simulated throughput of the Divert for a time period is greater than observed in reality for the same period. The data/logic issue appears when solving the problem. To rectify this issue, the input data for the movements of the Divert in FAST could be increased to encompass this scenario variation. However, new inputs would be required for this specific scenario and only for the Diverts after an automated test machine operation. This requirement for a new set of inputs could be identified as a logic change as a new element for this scenario requires definition. The inclusion of a new element takes the research back to a concept introduced in Chapter 2 (Figure 2-2). This question of increased complexity vs. accuracy benefits and resource requirements must be answered by the Model Stakeholders. The assessment of the impact of this inaccuracy is required.

FAST Input Parameters: Pre-stop Logic Variation

The FAST interface allows the modification of the Witness simulation program to be made. Importantly the column number and value of the input parameter entered can change the model logic. The Pre-stop existence is one such parameter. Element Pre-stops can be turned on or off in the simulation model by entering a ‘1’ or ‘0’ in the correct excel column in FAST. The existence of a Pre-stop before an operation can change its input and output logic. There is a difference between the modelled Pre-stop and one in the LAL. This is summarised in Table 8-13:

Table 8-13: LAL and Simulation Pre-stop disparity

Scenario	Simulated Pre-Stop Logic	LAL Pre-stop Behaviour
1	Operation idle No free space in output buffer Part will not enter element	Operation Idle no consideration of buffer status Part enters element
2	Element cycle complete Free space in output buffer No part at Pre-stop Element holds part	Element cycle complete Free space in output buffer No consideration of Pre-stop Element releases part

The consequence of scenario 1 in the simulation is an operation can remain idle and empty if there is a Part waiting on the Pre-stop and the buffer is full. This potentially means that, during a breakdown situation in a preceding operation, it could wait empty. In reality the operation would carry out the work content on the Part and wait full. The effect in the assembly line is to increase the storage capacity of the line by one Part (per applicable operation) during a breakdown of a preceding operation.

The consequence of scenario 2 in the simulation is an operation remains busy and full if there is no Part waiting on the Pre-stop. This potentially means that, during a breakdown situation of a proceeding operation, it could wait full. In reality the operation would carry out the work content on the Part and output it to the buffer and wait empty. The effect in the assembly line is to increase the throughput of the operation during a breakdown of a proceeding operation.

When either of these consequences is applied to multiple machines on a section of assembly line, the difference between the simulation and real system could be measurable in the throughput of the affected section. If this is a buffer section then the discrepancy between buffer behaviour knowledge of the real system stakeholders and the simulation outputs could account for doubt issues in this context. The benefits of the buffer (Appendix B) may not be simulated because of this logic gap. To solve this issue the Pre-stops can be turned off to allow the ‘Free Flow’ of the line to be modelled.

8.2 Existing Simulation Strategy

This section presents and analyses the current simulation strategy in Ford.

8.2.1 People

The current simulation strategy of Ford involves using various people to build, verify and validate the models. The simulation specialist takes primary leadership of modelling activities. The various people who build the simulation models using the FAST interface are the simulation expert, university students and possibly other employees from the productivity department. Constructing simulation models is time consuming and repetitive. Hence there are few people in Ford who compile the simulation models. The majority of the users of the simulations receive completed models with which to perform experiments.

8.2.2 Simulation Methodology

The current methodology to produce simulation models of an assembly line consists of Four Stages. The four stages are shown in Figure 8-22 using an IDEF0 Standard diagrammatic representation.

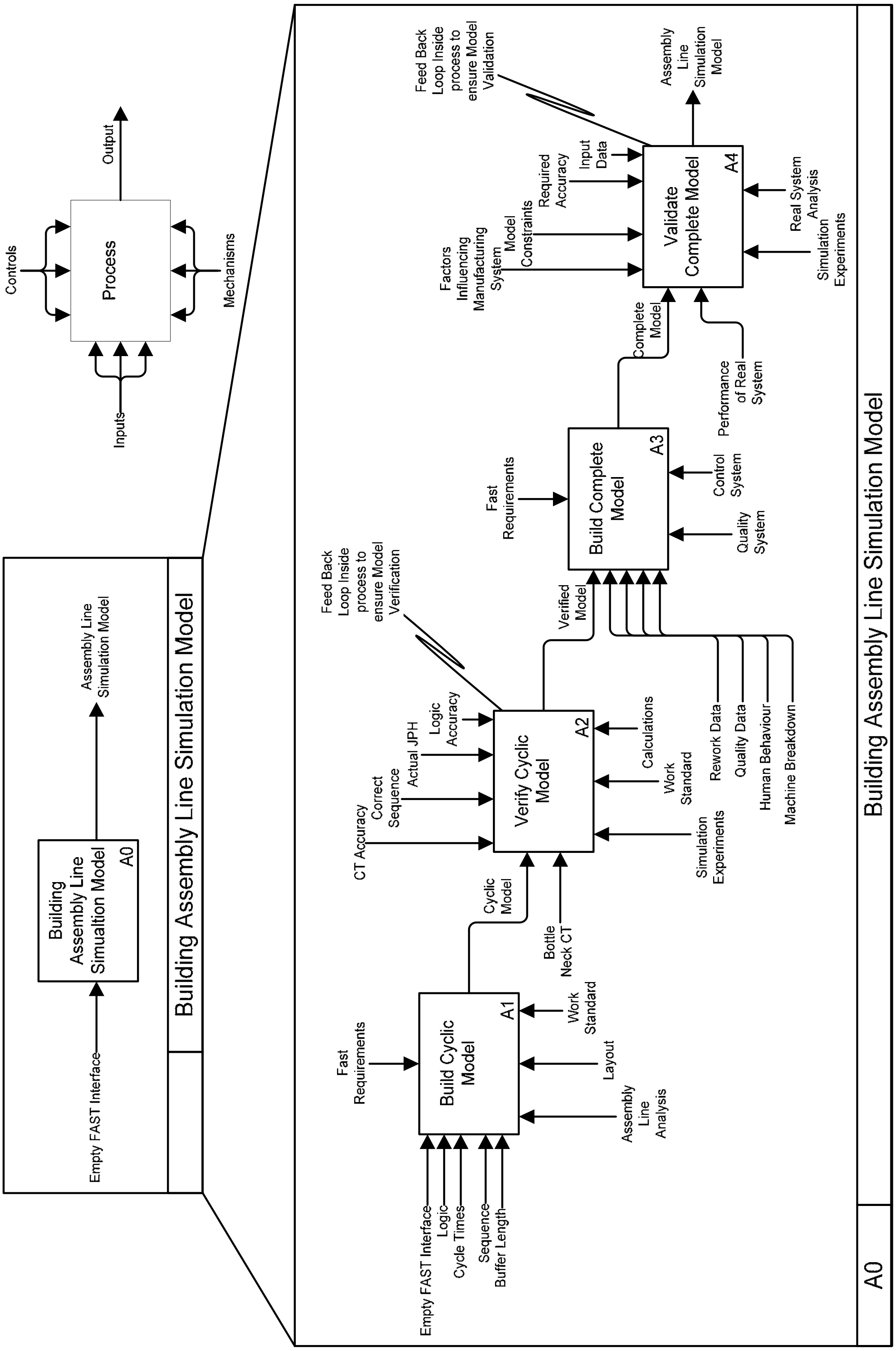


Figure 8-22: IDEF0 Representation of Current Ford Simulation Methodology

The current simulation methodology is an adaptation of the work carried out by Arguedas et al (2006) for and on behalf of Ford Motor Company. The simulations in Ford are built using the method, shown in Figure 8-22, through the FAST interface. A user of the simulation model requests an Assembly Line Simulation Model. The model supplied to the user is in a complete state with validated input data. The user has the ability to manipulate the data to test scenarios before implementing them in the LAL.

8.2.3 Analysis of Current Methodology

Acquiring knowledge of the current simulation methodology from previous projects with Ford Motor Company (Arguedas et al., 2006), meetings with stakeholders and observations of the simulation enable the completion of the SWOT analysis shown in Table 8-14:

Strengths	Weaknesses
FAST allows quick data change.	Assumptions not given while building.
Relatively easy to learn.	Relies heavily on accuracy of data (verification & Validation).
Uses estimated or standard data, reducing data collection time, increasing modelling speed.	If there is no installed assembly line systems analysis cannot be performed increasing errors and relying on layout, best guesses and validation with more people.
Does not require detailed logic knowledge to model interactions.	No guidance to analyse line.
Standard approach speeds up fault finding by expert.	Requires time to visit Assembly line for analysis.
Methodology is a proven approach.	Assumes all measured lengths can hold parts.
Opportunities	**Threats**
Provides room for improvement.	If the real system is updated simulation may become obsolete, no link to assembly line.
	Estimated or Standard data reduces confidence in output.
Building simulation models can be outsourced.	Lack of assumptions remove some credibility of method.
	No logic guidance could cause mistakes.
Users with little simulation experience can run experiments by changing data.	Relies heavily on input from many people, poor information may lead to many iterations during verification and validation phases prolonging the process.
	Lack of understanding of behaviour of model may mean validation phases not completed properly and force assumptions to be made.

Table 8-14: SWOT Analysis of Current Simulation Methodology

Examples taken from Table 8-14 of issues with the current modelling method follow:

Modifications	The LAL is changed and the simulation models are not updated. Changes can be made to the distances between operations. These distances represent buffer sizes in the model. If these are not updated in the model because of lack of communication then the model outputs may not be correct. The control system can be tweaked on request by team leaders. The control system can be changed to make the line behave in many different ways. When updates to the system are made they are not communicated to the simulation team.
Buffer Capacity	A use of the simulation model is experimenting with buffer capacity. Buffer capacity is derived from the Platen length and distances measured from facility layouts. These can be changed easily using the FAST interface. An issue is the Platen length is known and it is assumed that the Platens can stack up against each other. In the LAL a Platens total length increases when a Kitting Box (Appendix B) is added. The assumption remains that the Platens can stack against each other. In reality this may not be the case and parts use element stops to space the Platens apart. This may cause variations between the real and simulated line capacity
CML	The Continuous Moving Line (CML) operations (Appendix E) on the work standard do not include the total length of conveyor where the reduced speed is experienced. Careful knowledge about the CML is required so that the complete length of reduced speed line is modeled using dummy operations (Appendix E).

Addressing the weaknesses in the existing methodology could provide distinct improvements to the simulation methodology. While retaining the strengths, such as the proven approach, increase the opportunities presented by the current methodology.

8.3 Potential Strategy Improvements with SSD

This section identifies and analyses the potential improvements possible to the Ford simulation strategy.

8.3.1 SSD Benefits to Ford Simulation

Aligning the simulation process and defining it in the SSD reduces the potential for various stakeholders at different skill levels from interpreting and modelling the system in there own way. A more homogenous simulation strategy used and developed by stakeholders will dissuade them questioning the reliability of the outputs as they have a greater awareness of the modelling process. The principle of aligning simulation model production is pictorially represented below in Figure 8-23.

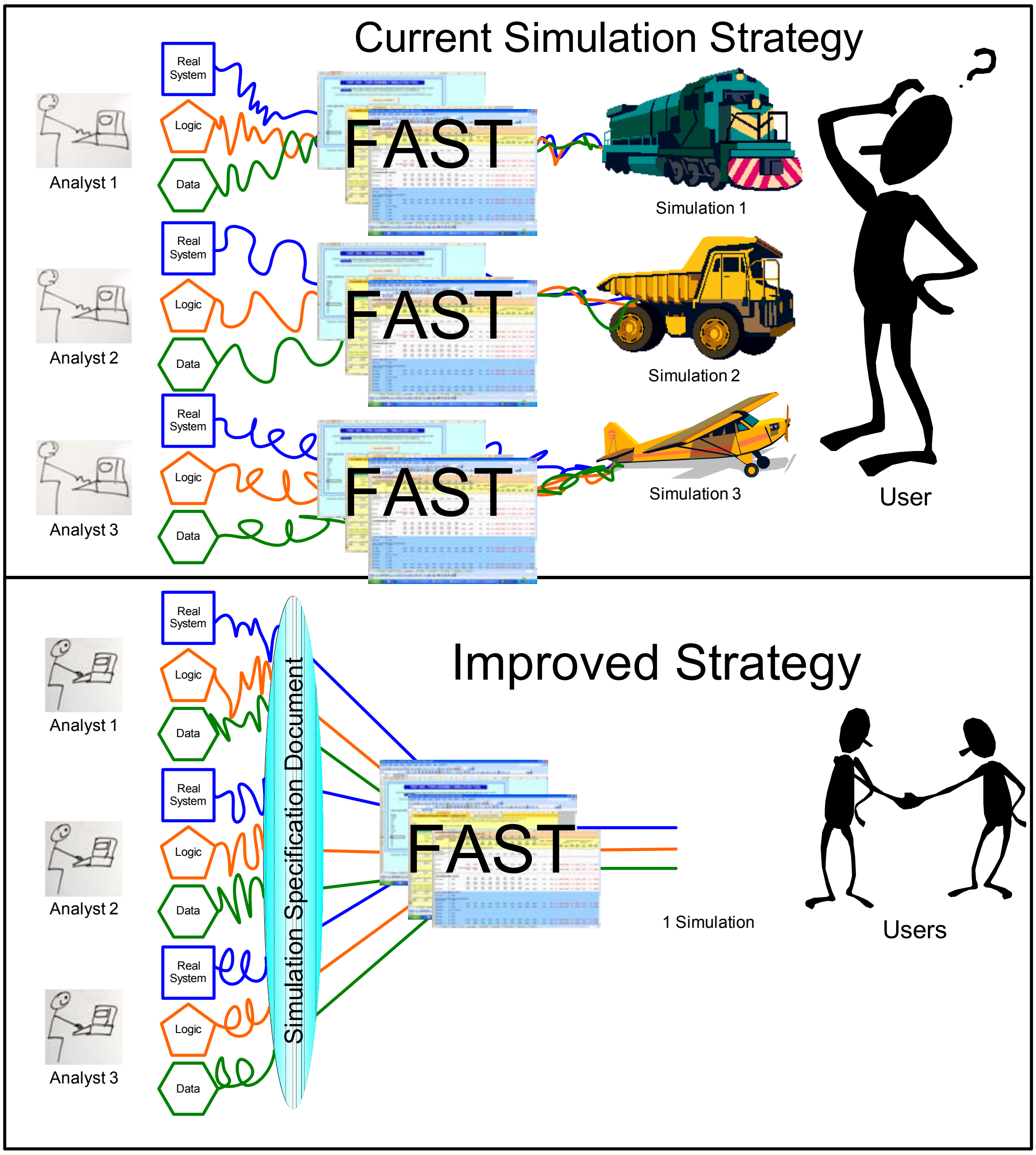


Figure 8-23: Comparison of Ford Simulation Strategies

Figure 8-23 demonstrates that the ability of FAST to homogenise the simulation process can be improved using the SSD. The logic understanding, system analysis and data accuracy are aligned by the SSD. The potential of the SSD allows different people to analyse systems and create simulations that stakeholders can have improved confidence in. The time to analyse the assembly line can be dramatically reduced by providing guidelines of the analysis.

The need to visit the assembly line could be reduced by changing the way the Layout is presented. The layout can include the element boundaries and expected element capacities. Experts in the relative systems can use the details on the element boundaries to quickly build a new style layout using standard tools and formats built into the framework of the SSD. The element boundaries are not intuitive, however, the elemental boundary philosophies are simple to understand, communicate and ease the comprehension of the modelling process. These and other assumptions given at the start of the modelling process remove some of the problems associated with not understanding the model behaviour.

8.3.2 Analysis of Future Methodology

The potential future simulation strategy using the SSD as a focus point during the simulation completion, proving and V & V phase removes many of the crucial sticking points associated with simulation in Ford. A SWOT analysis of the future methodology is shown in

Table 8-15.

Table 8-15: SWOT Analysis of the Potential Future Simulation Strategy in Ford

Strengths	Weaknesses
Reduces reliance on conceptual translation of reality into simulation model.	Initial Development of SSD and Methodology could be time consuming and labour intensive.
The flexibility of the web based SSD allows it and the methodology to be improved as the simulation improves and changes.	Complete SSD discussed requires central database and assocated systems management.
Assumptions communicated throughout SSD ensure consistency between analysts and stakeholders.	
Standard approach aligns analysts and stakeholders ensureing common model creation, use and analysis.	Accuracy of simulation model outputs continues to rely on accuracy of input data.
Solves buffer behaviour issues by defining part holding capacity not just buffer legnth.	
Opportunities	**Threats**
Going through the change process required to implement methodology increases awareness of the simulation model and associated benefits.	Benefits not felt by all departments involved and may be reluctant to spend time to complete their required input.
Changes to real system that require complete new elements can easily added by following standard analysis techniques.	
Saves resources as less outsourcing is required.	Will require investment justification, however quantitative measurement of payback difficult to prove.
Encourages collaboration between departments.	
Standardised approach increases users of simualtion models.	Inaccurate data could still mean model not trusted.
More accurate models from validation phase because of increased understanding.	If not linked to continuous improvement of Ford methodology the SSD could become obsolete, returning confidence levels to initial conditions.
Ensures longevity of Fords competitive advantage gained through simulation.	

The SWOT analysis in

Table 8-15 identifies some specific issues relating to modifying the simulation strategy. Witness and FAST already have re-usable components in them, however should the experts in these tools leave Ford and the knowledge will go with them. The specification document will reduce the time and money required to analyse the existing simulations or build new ones.

The SWOT analysis of the improved simulation strategy clearly shows the increased benefits to the Ford simulation strategy. The drawbacks and issues associated with reaching this strategy are not minor. The data requirements of the model are fulfilled by various departments in Ford. The potential SSD requires their initial contributions to build the required data fields into the SSD. This may require increased resource contribution (time and money) from these departments. Justification for resource requests can come from payback expectations. In this case the data providers do not use the simulation and may not benefit from the improved strategy. This has the potential to hamper any strategy improvements.

Justification may be required for extra resource from stakeholders and management. Quantified payback may be hard to justify. Qualitative payback may be achieved by considering the reduced time to make confident decisions.

The potential SSD discussed grew from the attempt identify a way to improve simulation confidence. A measure of improved confidence should be considered: 'To what level of confidence increase is required?'. If total confidence is the target, a complete SSD is the answer and the resource requirements are justifiable. However if the level is unknown (as is the case) then building and communicating different levels of the document may suffice. It was discovered that the three main areas of doubt came from:

- Input and Output Data Quality
- Modelling Assumptions
- Perceived Logic Gaps – (Solved with ALS)

Without a complete SSD the confidence could be substantially improved with documents similar to the ALS removing the remaining two areas of doubt.

8.4 Chapter Summary

This chapter aimed to record the collaborative process and results of disparity analysis of the simulation and LAL. The targeted collaborative review was not possible meaning potential, non-validated gaps were highlighted by the researcher. The boundary modifications and element definitions mean that the simulation logic correlates closely with the majority of real and simulated elements. There are some scenarios that occur in the real system that may not be logically accurate in the simulation model. Validation is required with stakeholders to assess the requirements to include these in the model.

The secondary purpose of this chapter was to identify potential improvements to the simulation strategy using a specification document. The existing simulation strategy was analysed for potential voids that could be filled by a SSD. The potential improvements using the SSD to the Ford simulation strategy were identified and discussed. The SSD could increase the accuracy of the representations and the communication of the important assumptions. The conclusion of the research is presented and critiqued in the final chapter.

9 Discussion and Conclusions

The focus of this research came from the clarification of an initial problem set by the industrial sponsor, Ford Motor Company. The issue presented suggests a lack of confidence in the simulation and its associated outputs used for decision making. A supposition of reduced confidence in the outputs stemmed from a perceived misrepresentation of the behaviour of the assembly line in the simulation model. The aim of this research was…

“Increase Confidence in Simulation Models of the Engine Assembly Lines within Ford”

The industrial problem solution targets the development of documentation to specify the real system in enough detail to identify gaps and close correlations in the underlying logic of the simulation. To complete an Assembly Line Specification and achieve the aim the following objectives were established:

1. To analyse and represent the Ford Lion Assembly Line logic.
2. To verify and validate representations of the Lion Assembly Line logic.
3. To develop an Assembly Line Specification.
4. To critically analyse the use of the Assembly Line Specification to improve the simulation Strategy within Ford.

The discussion of the research findings and comparison of them to the research objectives above are presented in this chapter. Recommendations to the sponsoring company are examined. Contributions to the knowledge of Ford in the research context are suggested. In conclusion, limitations and suggestions for future work are presented.

9.1 Research Findings

This section identifies the key findings from each stage.

Findings after Stage 1

Observations of the logic of the Ford Lion Assembly Line (LAL) can be effectively carried out observing ‘levels’ of detail, thus optimising the analysis. Starting from a high level of scenario actions through sections of the LAL, then focusing on a particular component and then the intricate actions carried out on parts in the system.

The LAL can be observed to be made of 14 repeatable elements. The repeatable elements can be combined in any order to build a representation of a complete assembly line.

The iterations necessary to produce flow diagrams showing the logic of a real system prove that modelling interactions is complex and depends heavily on scenario interpretation.

Findings after Stage 2

Deeper logic extraction from the real system is possible using a three check methodology employed in the control system. However, the depth of logic analysed and presented was deeper and more accurate than required in the simulation.

The conceptual structure of element boundaries in the simulation simplifies the representation of element interactions. The number of elements is reduced by including an output buffer in the element boundaries. Raising and simplifying the level of logic representations also reduces the number of elements.

The approach and representation of the logic was novel to the validating parties. However, the message was conveyed easily to the participants.

Findings after Stage 3

There is no standard approach to developing or presenting specification documents of simulations or assembly lines. Therefore, the novel development of one is required.

The Assembly Line Specification (ALS) does represent, in detail, the behaviour of the LAL in flow diagrams, sketches and textual descriptions. The simulation analyst can use the ALS as a tool to justify the simulation model logic behaviour to people familiar with the real system.

The ALS may not meet the full requirements of the stakeholders to completely dispel doubt surrounding simulation model outputs. The ALS could partially increase model confidence from its current level. A complete Simulation Specification Document (SSD) could be a tool to instate complete confidence in the simulations.

Simulation specifications have been found to be evolving into interactive web-based user guides. Therefore, a web-based SSD could potentially dispel doubt of the simulation outputs. The ALS is a component of this document.

Findings after Stage 4

Knowledge gained by the researcher of the simulation and the real system allowed the identification of possible logic gaps and correlations between the simulation and the LAL. The gaps and correlations are included in the ALS in Appendix E for the simulation expert to validate.

The simulated element boundaries correlate and represent the real system simply and accurately. The logic in the model works for the majority of observed scenarios.

The current simulation strategy may be improved by building the SSD into the day-to-day simulation activities in Ford.

The potential SSD could align peoples view on all the components required to build a simulation model from data gathering to logic analysis and from system interpretation to simulation running.

Justification of additional resources may be difficult due to the lack of quantifiable payback period. The payback justification may come from increased speed and confidence in decision making.

The communication of justified logic gaps, input and output data quality and model assumptions may be enough to increase confidence in Fords' simulation philosophy.

9.2 Research Findings Compared with Research Objectives

This section analyses the key findings in the context of the original objectives of the research.

Objective 1: To Analyse the Lion Assembly Line and Represent its Behavioural Logic.

The assembly line was observed using various tools and techniques with input from key assembly personnel. Important findings are that the assembly line could be broken down into elements and their logic identified. Mapping the interactions between the elements was aimed to enable the logic of a full line to be extrapolated. The interactions between the elements present representational problems as the interactions are complex and difficult to observe from the real system. The unbiased approach taken meant that the understanding of the line gained was slow yet progressive with each visit to the line revealing another layer of understanding.

The components identified in the LAL had an elemental approach applied to them. The elements' logic identified and represented using flow diagrams enabled Objective 1 to be achieved.

Objective 2: To Verify and Validate the Representations of the Lion Assembly Line Logic.

The depth of the logic analysed and represented in the initial diagrams was deeper than the logic required. The logic diagrams were verified and validated (V & V) and improvements suggested. This objective is a valuable milestone in representing the information gathered from the assembly line as the approach was approved by the simulation stakeholders. The direct involvement of the participants at this level enabled the alignment of the scope and detail of logic representations to the different perspectives.

The LAL control system has a different logic representation system that may be available for representing the elements. During the design of the LAL control system, the complete system logic may have been mapped out. There may therefore be a way of representing the system logic in a communicative style close to the target of the logic diagrams presented. The specifications of the control systems may present some strengths that were not included in the verified and validated logic representations.

The V & V stage of the logic diagrams provides strong justification that Objective 2 was met.

Objective 3: To Develop an Assembly Line Specification.

When attempting to achieve this objective it became necessary to alter the methodology. This was necessary as the findings from analysis and research of the document requirements to fulfil the aim identified that it could not be completely met with an ALS. The method was improved to include the identification of the content of a document that could fulfil the aim of the research. This document is referred to as a Simulation Specification Document or SSD. Completing the document would have taken the work out of the scope of the research as many other factors were required to be taken into consideration such as data integrity.

The Assembly Line Specification developed is in a .doc document and contains the verified and validated information required to identify gaps and close correlations between the actual behaviour of the parts in the real system and the logic used to build the simulated. The format of the specification document produced means that it is a large document. Developing the format more scientifically could provide ease of use benefits to the users. The strengths identified from Stage 2 of involving the stakeholders could be applied to the document to check the framework and content. Due to restrictions imposed out of the control of the researcher or Ford, this was not possible. Despite this drawback of the lack of submersion in Ford the document produced is strong and fulfils its role in Objective 3.

Objective 4: To Critically Analyse the Use of the Assembly Line Specification to Improve the Simulation Strategy within Ford.

The variation in the methodology required to meet Objective 3 had little impact on the method required in Stage 4 to meet this objective. The ALS was used to identify disparity between the simulation and real system and the simulation strategy was effectively analysed using the proposed SSD.

The ALS is used to compare what is programmed to happen within the simulation model and what happens in reality. The comparison was possible due to researchers' knowledge of both the simulation and the LAL. If there are any gaps between the two, these can be validated and rectified by the simulation expert using the ALS. The results are that the simulation analyst can confidently justify the model using the ALS.

An important, yet absent, component of the current strategy (identified through communications with various stakeholders) is the omission of assumptions from the simulation information given to users. The addition of a complete list and definition of the assumptions could instil the desired confidence in the simulation model. The assumptions used to analyse the assembly line and build the ALS have therefore been included in the specification for these reasons. The complete SSD would lead the analysis of the line and simulation output to areas where doubt exists. The stakeholders can then prove the accuracy of the model and indeed make informed and confident decisions based on the model outputs.

By meeting the four objectives, the simulation model was identified to contain many correlations with reality with some key gaps in the logic. These were identified using the ALS and are recorded in it. The current simulation strategy within Ford contains some weaknesses and improvements have been suggested in the form of a SSD with the important potential content identified and approach critiqued.

9.3 Recommendations to Ford

This section introduces some recommendations to Ford to increase confidence in current simulation models. Applying the modifications is suggested to enhance the simulation philosophies. The suggestions are based on the process followed, results gained and analysis of them.

9.3.1 Short Term

Communicate logic assumptions when distributing pre-built simulation models to users.

Identify, with real system experts, free flowing assembly lines and those that use the Pre-stop to change the input and output logic of an operation.

9.3.2 Medium Term

Validate the identified gaps recorded in the Assembly Line Specification with the knowledge of the people of the real system and simulation experts in order to identify whether changes to the model are justified.

Identify new ways to represent the lines on a special layout that identifies the different elements required for modelling.

Identify buffer capacity and calculate lengths of conveyor for graphical representation purposes in Witness.

9.3.3 Long Term

Involve all stakeholders, collaboratively developing a framework and web-based Simulation Specification Document that allows the rapid extrapolation of information required by a particular user or stakeholder.

The simulation and Simulation Specification Document can be linked to the continuous improvement drive through the Web interface. It must be kept up-to-date and allow the specification to be automatically updated so enabling the simulation models to be a fair and current representation of reality.

9.4 Contributions to knowledge

This research provides Ford Motor Company with a documented account of the issues faced when analysing a real system and an unbiased record of the possible drivers behind the lack of confidence in the simulation model.

The cross-section of literature reviewed identified the lack of a standard approach to defining and developing simulation specifications. This research presents an approach to defining the content of a document and the real system components. The importance of including all assumptions is proven through the completion of the methodology.

The use of an existing assembly line and simulation tools to identify the logic issues in simulation confidence has not previously been addressed in literature. This research identifies confidence issues relating to the specific case of the Lion Assembly Line that may be relevant in other fields of application.

The concept of how the interpretation of the behaviour of an assembly line can affect the confidence in a simulation model has not been previously discussed. The solution to aligning interpretations of the real system using a specification document is a novel use to solve this specific problem.

9.5 Limitations & Future Work

This section presents some limitations imposed by the scope during the completion of the research. Possible solutions to these limitations could be identified from further research, two examples are given.

9.5.1 Limitations

The progressive collection of the logic data would have been accelerated and permitted a greater understanding of the line had total submersion in the assembly line been achievable. Total submersion may also have allowed may more scenarios be identified.

The elements used in the ALS are present in the Lion Assembly Line studied. The simulation elements are applicable to engine assembly lines globally. However, the elements identified were not validated with other assembly lines to ensure that they are correct and widely applicable.

During discussion with Ford stakeholders' the validity of the simulation input data was questioned. This subject was not broached during the completion of the research and appears to be a vital constituent of the model doubt.

9.5.2 Future Work

Data input

Real-time data inputs where suggested to increase output confidence. An investigation to measure the difference real data makes to the model could be carried out. The deviation required from the current standardised data before effects are shown in the model output could be investigated. This could be specified in a Data Specification Document so that people can have faith in the output when the data deviates from the standard. Literature and stakeholders agree that data is an important part of the modelling phase, particularly with FAST as it is data driven. A similar research project to specify the data in the model should be carried out.

Completing the Simulation Specification Document

Producing the full specification document in Ford would be very resource intensive and time consuming. Future research projects could identify the content missed from the specification. The identification of potential requirements for a complete web-based document using stakeholder inputs could be carried out.

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Appendix A Flow Diagrams

The logic of the elements is represented in flow diagrams. The flow diagrams have processes and decisions points. The flow diagram approach is used as it is familiar to many people within industry and can use a language that is tailored to the application and stakeholders.

Logic can be recorded and communicated in textual logic code using textual representations. This is not however a good way to communicate complex interactions as the length of the documents and the amount of words make it heavy on a reader to use. This is unless the user would like to copy it into a simulation model. This is not the case the specification of the logic is aimed to be a communication tool, simple flow diagrams will enable this to be so. The textual representations include words such as IF, THEN and ELSE, but not restricting to these. After these key words there are action words where an activity is performed, this can be represented in flow diagrams as a question and then an activity.

A flow diagram must have initial conditions of the logic which set the datum where changes in state of the part and the element can be compared to and return back to. The initial conditions are returned back to as the elements are cyclic. An example showing the flow terminology is shown in Figure A-1:

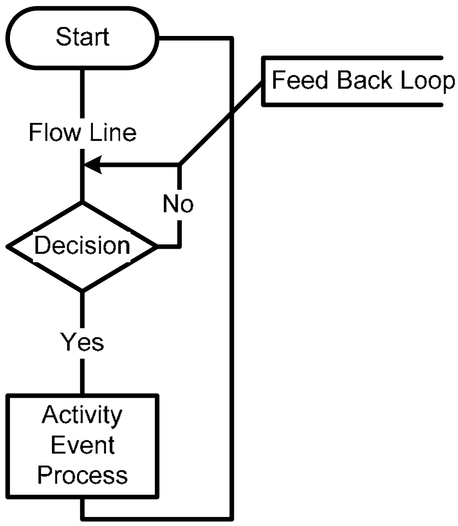

Figure A-1: Applied Flow Diagram Symbols

The decision diamond is where the logical questions are posed; the questions passed are worded to give two possible answers: “Yes” or “No”. This simple method of asking questions can determine more complex decisions when representing the flow in the simulation code language.

Appendix B Lion Assembly Line

This appendix introduces components mentioned in the main body of the research. Additional information may also be found in Appendix E.

B.1 The Facility

The assembly line is in a configuration composed of different U-Sections as can be seen from a high level in Figure B-1. The core component of the line is a moving conveyor with rollers. This moving conveyor follows the bold lines indicated.

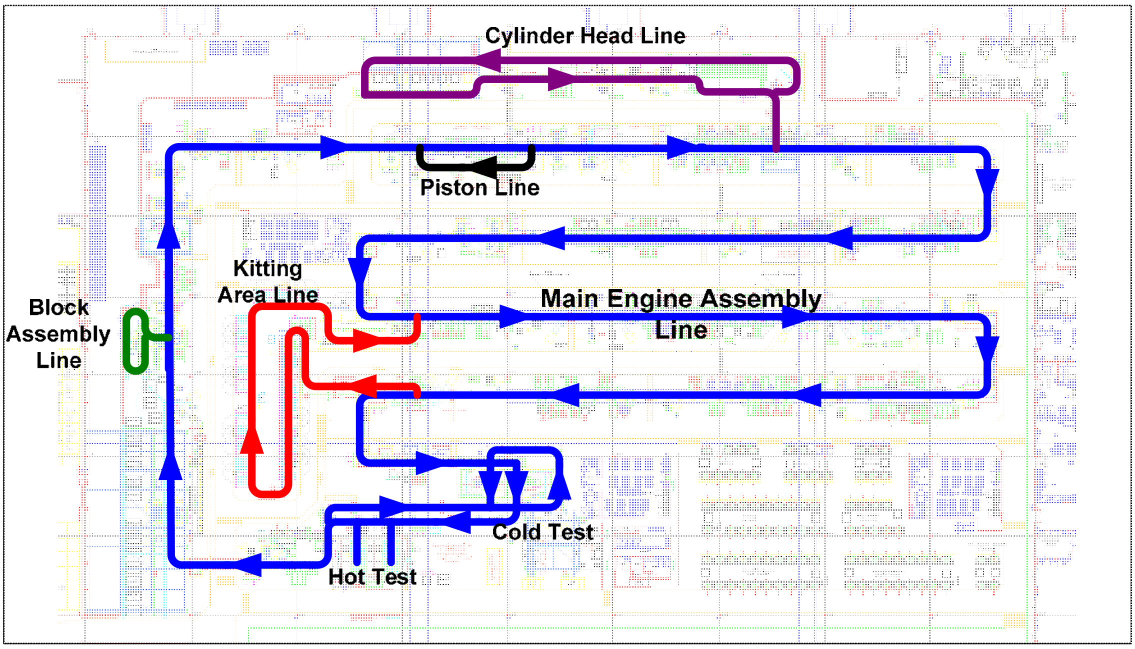

Figure B-1: Lion Assembly Line Showing Main and Sub-Lines

Figure B-1 shows that the complete Lion assembly facility is composed of a main and sub lines. In these components that the engines require to function are prepared for assembly onto the line in the correct sequence. There are also other smaller sub-assembly operations at an increased level of detail.

The Lines can be crossed at different points by material transports and workers at strategic crossing points.

B.2 Parts and Platens

The Lion Assembly Line assembles different derivatives of “V” configuration engines. The derivatives are for different customers; PSA, Land Rover and Jaguar. The different derivatives follow the same loop with a possible variation in some of the operations.

The engines and the main assembly components that flow on the Block, Head, Kitting and main line are mounted on platens. The platen is a device that allows the components to be mounted on the moving conveyor and manipulated at the operations or by specific pieces of automation. An example of an engine block and platen is shown in Figure B-2. Operations can be carried out on the platen by stabilising the whole device or removing the component and stabilising it within the operation.

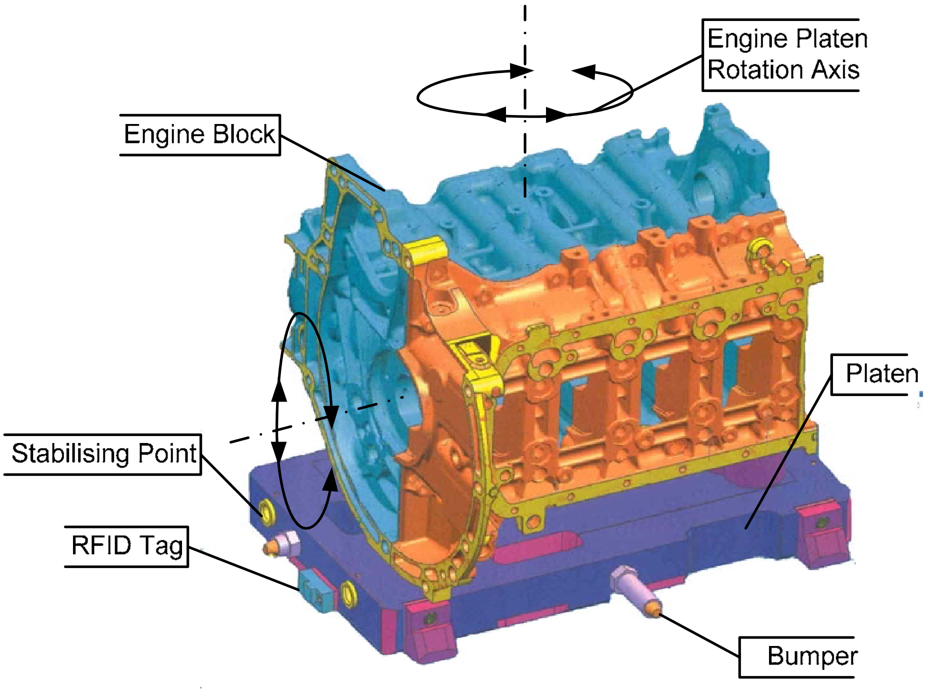

Figure B-2: Engine Block Mounted On Platen

The platens used to mount the engine on them in the assembly line are more complex than this example as the engine can be orientated on the platen through different rotational axis (Figure B-2). This allows the complex assembly procedures to be carried out efficiently and ergonomically by the operators.

B.3 Index time

A line balance time is calculated using the Demand, Working hours available and efficiency of the line. This line balance time is the maximum cycle time of any operation to carry out its task. The cycle time plus the time taken to transport one part from one operation to the next is the index time. The index time is given on the work standard. If an operation has the possibility of going over this time the work content is reduced and the excess shared with other operations.

B.4 Hot and Cold Test

The hot and cold tests have loops of line that can send engines back to a previous stage in the line as required. This accounts for the complex pattern of line around these to sections in Figure B-1.

B.5 Materials Transport

Materials transports are not included in the analysis of the system as they do not perform any direct effect on the parts. The only direct effect that could be possible is the incorrect delivery of parts of the lack of parts from the system. The example facility under study uses many well proven manufacturing practises to enable the line to be as cost effective as possible in terms of uptime and waste. The material delivery system is assumed to deliver the correct parts at the correct time to the right operation and so can be omitted from the analysis. If this was not the case a separate study of the material handling could be beneficial.

B.6 Operation

An operation waits for a part to arrive and usually has a stop and an intermittent conveyor that can be stopped and started to give more stability to the part of platen as the actions are performed on them.

B.7 Buffer

There are two different applications of the term Buffer in Ford. There is the simulation term discussed in Section 6.3.3 and the one applied in the real system. The Buffer terminology in the real system applies to designated area called Buffer Zones. These zones do not contain any operations only pieces of automation. The buffers in these sections are used to smooth the flow out between operations if there is a problem before or after the buffer.

The buffers are used to smooth out the flow and increase the JPH output of the Line. The buffer capacities are monitored by the team leaders using large LED display boards. Components such as Diverts, Lowerators and elevators are referred to as buffers on the Display boards in the assembly facility.

B.8 RFID Antennas

RFID is used on the assembly line to identify which part is at what position, its location on the line and what operations are to be performed on it. Some components within the system contain antennas for read and writing information onto the platens. It takes a fixed time for these to be read. There are elements like this that have variations that make them special.

Appendix C Control System Overview

C.1 Sensors, Actuators and PLCs

The sensors activate as a target carries out or completes its movement, the output generated goes to a (Programmable Logic Controller) PLC and the PLCs are major components of the control system. The PLC now has an output on a specific address based on this sensor input. A PLC on another Element is looking for the address on this PLCs output contact to change state. The change in state allows the PLC to drive an output to make a change somewhere else in the system. Operations that are next to each other may not necessarily share the same control system and may even be hard-wired together.

The PLCs in the controls systems can be configured:

- One (element) to One (PLC)
- Many (elements) to One (PLC)
- One (elements) to Many (PLCs)

As an example; the assembly line has different Zones, the conveyor in each zone is monitored by one PLC, if any part of the conveyor fails in this zone the all the conveyors will stop.

C.2 Control Element Boundaries

The concept of elements is not used in controls terms. The controls perspective looks at the processes that are required to occur and how to manipulate the signals or build new signals from sensors to actuators to allow the process to occur. In the control system the components are not split into elements but networks of control communication.

C.3 Structure of Controls Diagrams

The basic structure of control logic is the theory of checking:

- Check if something can be done
- Check if something is being done
- Check if something has been done

If none of these is true the system will loop round until the actuator makes it true, Figure C-1. At the same time as this there are errors that can appear for each check until they are complete. In the control system these checks are carried out at a high level of detail so the error messages of them not being completed cycle so fast that they are not required. At each of the checks there could be a time delay so that if the check is not satisfied within the time limit then an alarm signal can be generated.

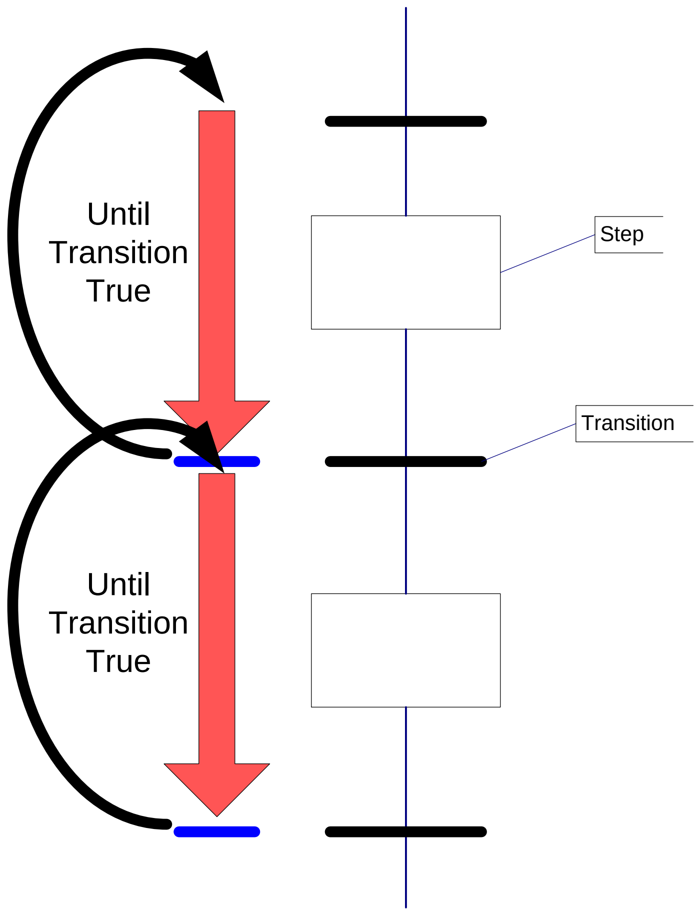

Figure C-1: Controls System Logic Perspective

The Transition in Figure C-1 behaves as the decision points in the flow representations of the logic. Once it is true the next step can occur and a message is produced.

The control system is used to check what an element is doing and at what stage it is at. A message is produced for each step that it is carrying out. |A step being carried out is reliant on another being finished. If the other is incomplete nothing will happen and a diagnostic message is displayed on the element Human-Machine Interface (HMI). The diagnostic messages are given a priority with the highest priority being displayed on the HMI. The steps and transitions are broken down into further stages. The transitions are ladder logic and the steps are function blocks that are linked to text blocks in code. The code is protected by vendors.

Appendix D Ford Simulation Package

D.1 FAST

The simulation is run using a Visual Basic and Excel interface. The interface links into the Witness program running in the background. In fast there are many parameters for the control of the different elements. The Excel interface can be observed in Figure D-1:

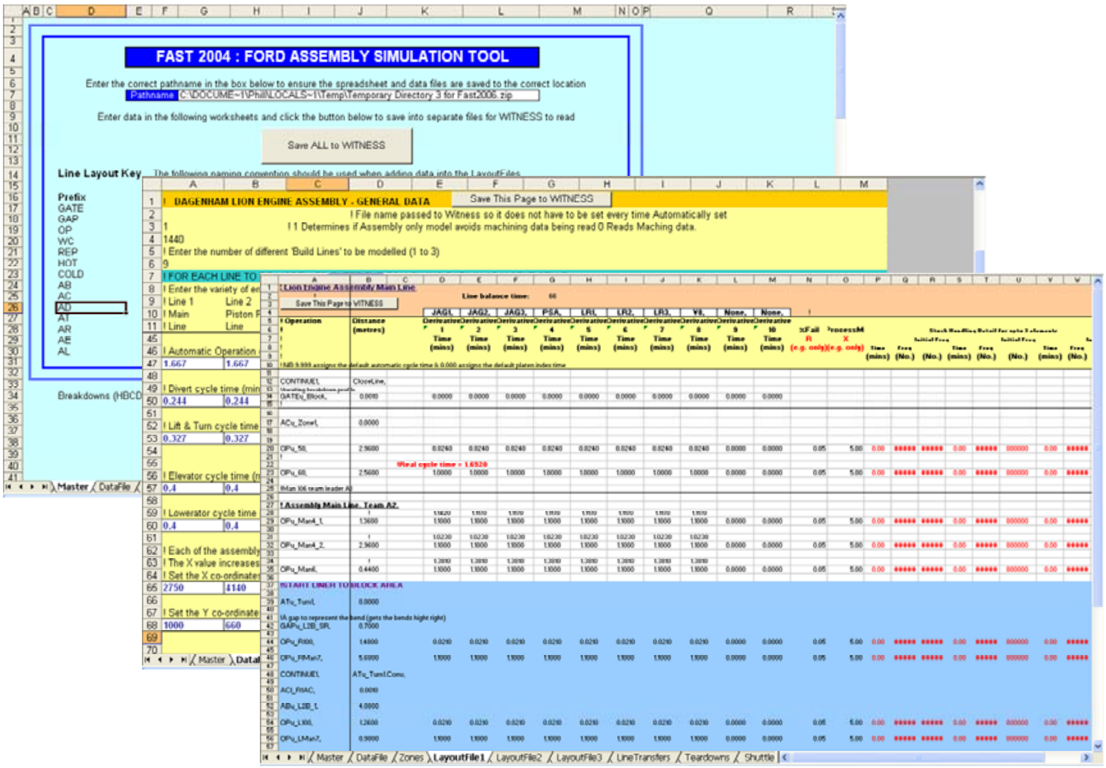

Figure D-1: Examples of the Fast Interface

Fast is a generic interface designed with the ability to model Fords' assembly and machining lines. The detail of which system it is determined by the data put into this interface.

A user does not have to write any complex logic as the logic is fixed within Witness. The user selects which logic codes in Witness to apply to the model by the input data that is entered into FAST.

D.2 Simulation Outputs

The simulation outputs that are used to make many decisions are Jobs per Hour (JPH). The jobs per hour outputs can be affected by many different variables. The JPH accuracy of the simulation models used relies heavily on the data input into the model. The behaviour of the line in the simulation model relies on the logic information that is input into it. The logic information can change how the line ebbs and flows, builds queues and starves operations. The logic and data can affect the operational throughput when focussing at a few operations.

The simulation is used generally to plan the people so inputs and outputs are generally focused towards maximising the productivity of people. This is an important factor in the assembly line as there are a lot of people and the wages are expensive requiring maximum output from them to give them the ability to make engines cost effectively.

D.3 Simulation Inputs

There are many data distributions that are input into the model. It is beyond the scope of the research to go into detail of the data. Cycle times, Breakdowns and part quality data are the most dominant in the model inputs. The order of the processes is dictated by the order in which the information is input into the interface.

D.3.1 *Buffer*

The buffer is a length of conveyor with no special conditions associated with it that can hold a dictated number of parts. The buffer size is set by the length of the conveyor available. In the model it has the following properties:

- Length
- The length of a platen is known and so the capacity of the buffer can be calculated.
- Platen driving speed (roller speed)

The buffer length, and hence capacity, comes from measurements of the assembly line layout. There is one platen on the main assembly loop every 1.8m when the kitting box is on its stanchion. Programming within the model recognises the points on the line when the kitting box is not on the line, the capacity of a buffer with the same length could therefore increase.

D.3.2 *Operation*

An operation pulls a part from the pre-stop position if there is space in the buffer. This is carried out using some Witness logic code. The operation has a cycle time based on the part type that is operated on, known as the derivative.

An operation has data information associated with a percentage failure rate of a poor quality part. There is a maximum re-process time associated with breakdown information. If it takes longer than this then the part will be ejected at the next Divert/Spur. The part continues at each proceeding element for the allotted index time until it reaches the Divert/Spur.

In FAST the input parameters are based upon an operation. An operation has the largest number of variables. Depending on the data, different elements can be modelled. The different data in FAST gives different elements and Logic in the Witness model. The names of the elements are also different by giving the prefixes in FAST.

D.4 Element Modelling

The elements can be modelled with or without pre-stops and with buffer capacities of zero. This element modelling method is used when there are at least two elements next to each other. An operating part of an element will always PUSH to the buffer using a simple rule if the buffer is present. If there is no buffer after an element then the element has conditions that must be fulfilled before it can push to the next machine.

The pre-stops can be turned on or off in the simulation with an input through FAST. If a pre-stop is off then the parts are in free flow and can flow, ebb and empty out. If the pre-stops are on the system will not empty, parts will be held in the machines until one arrives.

Appendix E Assembly Line Specification

Lion Assembly Line

Specification

Written and Compiled by:

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Cranfield University

In conjunction with:
John Ladbrook
Ford Motor Company

Specification Document Contents

List of Figures

List of Tables

E.1 Introduction

This document presents a specification of the real system logic for the Lion Assembly Line (LAL) specification of the logic is how the machines and pieces of automation work in the real systems.

To build a simulation model an interpretation of the real system logic is necessary. A comparison of the real logic and the simulation interpretation is also presented.

E.1.1 *Aim*

The aim of this document is to allow a reader to understand the behaviour of components of the Lion Assembly Line (LAL) in order to understand the real system elements and how to represent them accurately in the simulation model.

E.1.2 *Objectives*

To achieve this aim several steps have been followed:

- Defined an approach to specify the real systems
- Break down the real system into elemental components
- Diagram and explain the logic for each element
- Compare key real system elements with logic with the simulation logic
- Present general issues related to real ancillary logic and simulated logic
- Present specific issues for LAL logic and simulated Logic

E.1.3 *Real Element List and Definitions*

In this section the Real system elements are defined and a glossary of terms is presented to be used throughout this document.

E.1.3.1 Real Element Definition

Table E-1 presents the real elements, for each a brief description is provided.

Table E-1: Real System Elements

Real System Terminology			Brief Description
Automation	Single Part	Forward Conveyor	A section of conveyor that transports a part towards the end of the line.
		Forward & Reverse Conveyor	A section of conveyor that transports a part towards the end or start of the line.
		Road section Conveyor	A section of conveyor where a part cannot stop to allow vehicles to cross the line.
		Walk Over Conveyor	A section of conveyor where a part cannot stop to allow people to cross the line.
		Bend Conveyor	A section of conveyor that changes the direction of the line.
		Turntable	A section of conveyor that actively accepts a part and changes its direction onto a set section of conveyor.
		Divert	A section of conveyor that actively accepts a part and changes its direction dependant on an input.
		Spur Conveyor	Platen insertion or extraction using a straight conveyor attached to a Dirert.
		Orientator	A section of conveyor that changes the orientation of a part relative to the conveyor.
		Elevator	A Section of conveyor that raises a part from the starting conveyor level.
		Lowerator	A Section of conveyor that lowers a part from the starting conveyor level.
	Multipart	Forward Conveyor	A section of conveyor that transports multiple parts towards the end of a conveyor.
Operation	Manual	Manual	An operation carried out by a person on a stationary part.
		Continuously Moving	An operation carried out by a person on a continuously moving platen.
		Kitting Loop	An operation carried out by a person on multiple platens.
	Semi Automatic	Cold Test	An operation that requires fixtures and fittings applied to the platen before an automated cold test sequence is performed.
		Hot Test	An operation that requires fixtures and fittings applied to the platen before an automated hot test sequence is performed.
	Automatic	Robot	An operation carried out on a stationary platen by a robot.
		Machine	An operation carried out on a stationary platen by a Machine.
		Transfer Machine	A multiple operation carried out on multiple platens at the same time.

Table E-2 presents other components of the system that are not in an element family.

Table E-2: Other Elemental Components

Others	Stop	A device used to prevent a platen from travelling on a piece of automation
	Pre-stop	A device used to prevent a platen from entering the boundry of a piece of automation or element.
	Antenna	RFID Read/Right Sensor to transfer information between Platen and quality control system.
	Zone	The amount of automation that a control cabinet can handle defines the legnth.
	Marriage point	When a part passes over this specific Antenna a signal is sent to another part of the line to sequence the components to assembly onto the platen
	Quality Extraction	Parts taken from line using a spur and divert to workshop for component strip back or re-work
	Quality Insertion	Parts are re-entered into the line using a spur to enter the line.
	Breakdown	An operation or piece of automation stops performing its function.
	Changeover	Applies to a transfer machine that requires different tooling for a change in part derivative.
	Line Transfer Gantry	An overhead transportation system that moves a part between sections of conveyor.
	Line Transfer Operation	An operation that removes a part from one line and enters it onto another line.

E.1.4 *Key Term Definitions*

Table E-3 lists and describes briefly the terms used in this document. The aim of this list is to prevent any miscommunication through the document.

Table E-3: Vocabulary Definitions

Term	Description
Antenna	RFID Read/Write Sensor.
Automation	Automation is the generic family name for a piece of equipment that is only used in the transportation of the platen around the system.
Bend	Used at the end of a section of line to change the direction of the platen.
Boundary	A conceptual limit of an element of the real or simulated system.
Breakdown	When a process does not complete due to a failure in the real system.
Buffer	A length of conveyor that can hold a number of parts, determined by the length before the next pre-stop or element.
Changeover	The process required to change an element prior to a change in derivative.
Check Buffer	Space in the Gantry Buffer allocated for manually checking parts.
CML	Continuously Moving Line.
Conveyor	A piece of automation that transports platen through system.
Conveyor Forward	Conveyor transports part towards end of line.
Conveyor Reverse	Conveyor transports part towards beginning of line.
Cycle	An interval during which a recurring sequence of events occurs.
Cycle Time (CT)	The time taken to complete a recurring sequence of events from a fixed starting and ending viewpoint.
Derivative	A variation in the part from the generic base.
Dog Tooth	Component of a CML that hooks onto the platen.
Element	A piece of equipment or simulation module that is repeated throughout the real or simulated system that interacts with others to make a complete system.
Flow	The movement of parts through the system.
Index time	The time platen is held in a pitch.
Inject	The process occurs to insert a part onto the main line.
Interaction	The exchange of information and/or parts between elements of the real or simulated system.
Load	Load Action could be release pre-stop and in some cases start conveyor.
Logic	The sequence of events that take place.
Operation (OP)	The part in the operation is physically changed. Material could be removed in the case of the machining line. Components could be added in the case of the assembly line.
Marker Operation	A small operation where part codes are inscribed on components
Part	This is a part in the system and has operations performed on it, such as: Cylinder Block, Cylinder head, Kitting Boxes, Pistons, Crankshaft or Camshaft.
Pitch	A length of conveyor that can hold one part for an operation
Platen	The part is mounted on a platen and transported through the real system on it.
Pre-Stop	Stop on a conveyor before a component of an element of the real system that carries out a process on a part.
Process	The activity that occurs in the flow diagrams to changes or maintains the a part or an element in a busy state or changes from busy to idle.
Reject	A process occurs to take a part from the line.
Reset	An element is set back to it's initial conditions.
Space	A unoccupied section of conveyor that has the capacity for one or more parts.
Stop	Device on element that stops the platen.
Travel Time	time for platen to move completely through one pitch.
Wait	The current state of the element is held.
x Parts	Number of parts is dependant on element under consideration.

E.2 Logic Analysis Approach

To describe the logic of the real system elements listed, it is necessary to present the simulation background. Two main issues that dramatically impact on the representation of the real system element are:

- Depth of Logic
- Element Boundaries

E.2.1 *Assumption*

The following assumptions where made when compiling this document:

1. When a scenario is observed on an element or group of elements, it is assumed that this is a normal occurrence and can be applied systematically to those elements.

2. Observations of the logic of an element are applied to elements of the same type. Validation of the logic with every element of the same type is assumed not to be necessary as the elements look and behave the same. It is not physically possible within the time constraints to observe every element in every situation.

3. Input from Ford employees who know the lines was necessary as not all scenarios where directly observed. The input was validated, however it is assumed that the information given is correct and represents the real system.

E.2.2 *General Simulation Approach*

The simulation approach is specific and may require explanation to be understood. Roughly simulation models enable the observation and experimentation on the flow of parts in the real system. How parts travel through the LAL can be examined using simulation models.

E.2.2.1 Simulation Focus

Basically simulation looks for how parts travel from one operation to another, the travel time and the operation time. Simulation is time orientated and requires in information on the route followed by the parts.

In the case of the LAL, the simulation model needs to know:

- The part flow
- Travel time between operations
- Loading scenario for an operation
- Unloading scenario for an operation
- Operating Time
- The impacts of ancillaries (e.g. Breakdowns and Changeover etc)

The logic of the complete system is composed of all scenarios, the part flow and the impact of ancillaries. A step in the logic takes a time equal a transportation time, operation time or time of an ancillary.

E.2.2.2 Logic Level

The level of the logic is the depth of the explanation of the real system behaviour. Simulation pays attention to events which spend time since these will impact the parts' flow. The level of logic required for the simulation is a level where processes which takes time are described. This can be presented in following Turntable example:

<u>Turntable Example</u>

The Turntable loading process requires two steps:

- Start Conveyor
- Open Pre-stop

These two actions do not spend a significant time from a simulation point of view. These two actions describe the necessary step to realise the process of loading part into Turntable. Simulation does not take into account this level of logic detail where a process is broken down into its sub-processes. This is because these sub-processes do not always take time.

E.2.3 *Element Boundaries*

The element boundary is a very important issue. Boundaries are the limits of what is internal and external for an element. The boundary of an element will affect its logic and can dramatically affect the interactions between elements. This makes the establishment of the element boundaries key for the specification of the real system.

E.2.3.1 Simulation Boundaries

Simulation element applies boundaries which are not "Spontaneous", i.e. an element boundary used in the simulation is not intuitively recognisable from observation of the real system. In the simulation interpretation every real element is considered as an operation that takes a Cycle Time.

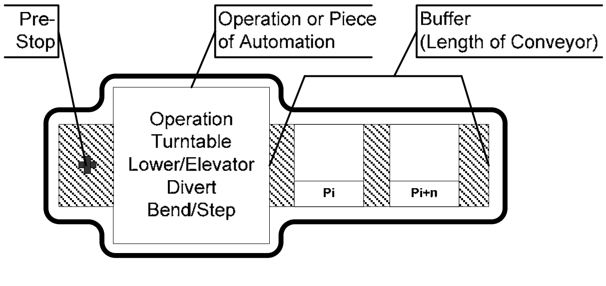


Figure E-1: Simulation Element Boundaries

The Buffer size of an element can be Zero if the elements are back to back. This also means the there can be no Pre-stop as the elements internal stop can act as the Pre-stop. This means that when a cycle finishes the part is transferred to the next operation directly if it is free.

There are several justifications for using this approach, some of which are presented in below:

<u>Real system analysis is simpler</u>

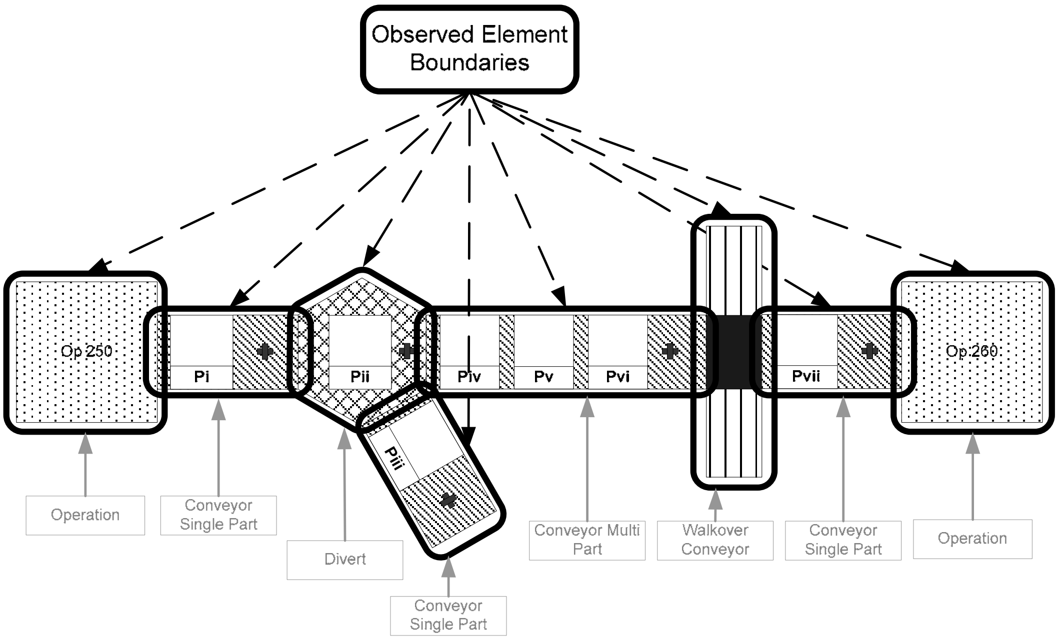


Figure E-2: Assembly Elements with Intuitive Boundaries Applied

Figure E-2 shows a section of Lion Assembly Line, the “Spontaneous” boundaries give 8 elements.

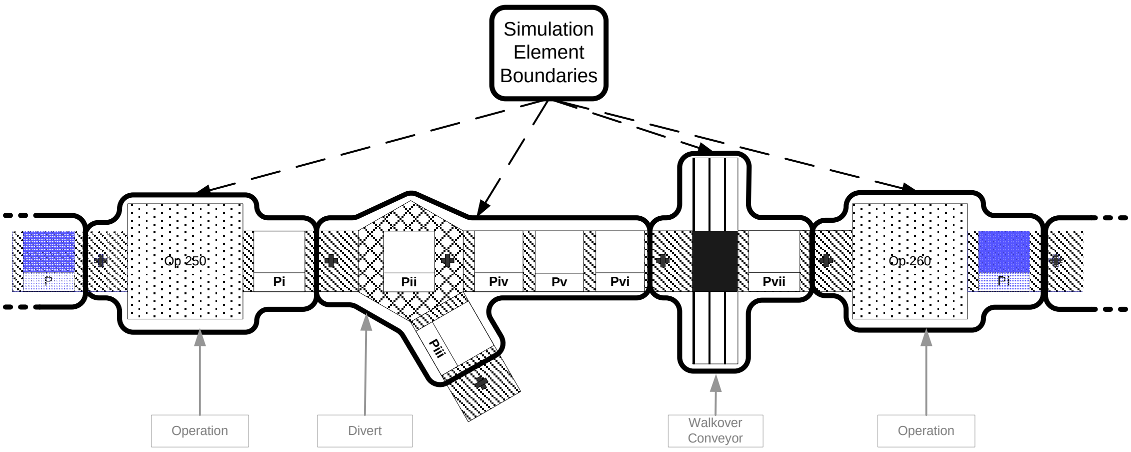


Figure E-3: Simulation Definition of Element Boundaries

Figure E-3 shows the same section of Assembly Line using the simulation boundaries; the result is the identification of 4 elements.

For the same section changing the boundaries of the element reduce notably the numbers of element, this makes the real system analysis simpler.

<u>The interaction between elements is much simpler</u>

From studies, the interaction between elements is a complex issue, with the previous boundaries. With the simulation boundaries no real interaction are required other than simple logic rules. The number of elements has been reduced and hence the number of interaction has also been reduced.

<u>The comparison of the simulation and real system logic is more direct</u>

Applying simulation boundaries makes the comparison of the real system is easier as the elements are compared like with like.

E.2.3.2 Updated Element List

The number of elements has been reduced; Figure E-4 shows the Simulation elements and the Real System logic elements that have been grouped together for simulation purposes.

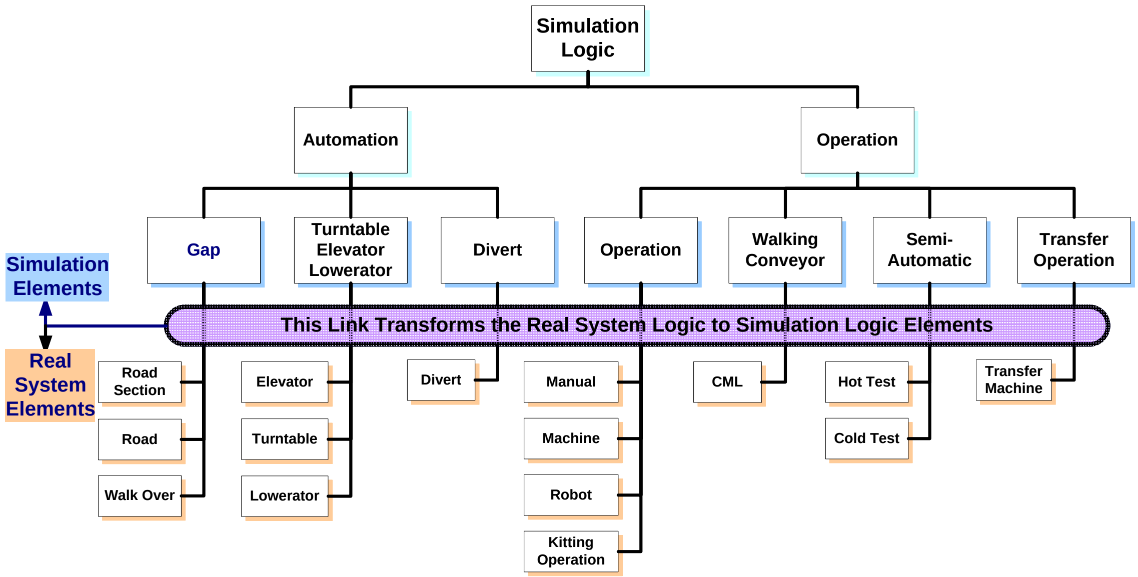


Figure E-4: Simplified Element List

E.2.4 *Flow Diagram Definition*

The flow diagram is the selected tool to illustrate the real logic of the system. Standard flow diagramming is used as shown in Figure E-5:

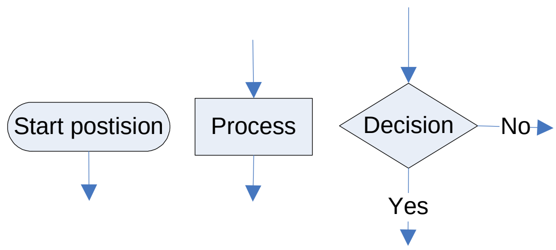


Figure E-5: Standard Flow Diagram Syntax

Starting Position: All elements have a starting position. They return to this state cyclically. Start position is the initial statement of an element.

Process: Processes are actions. As describe above, processes spend time to be performed. These processes are completed processes, in action like “rotate turntable” it is considered the action is started, carried out and finished.

Decision: Decisions ask questions. Many questions are asked in cycle, this means the system asks questions until obtaining the answer which will unblock the element. It obtains the right condition before going further in the flow diagram (go to the next process or decision).

To help the understanding of the diagrams a colour coding is used. Figure E-6 illustrates the colour code. The Element Body could be an Elevator, Lowerator or Operation etc.

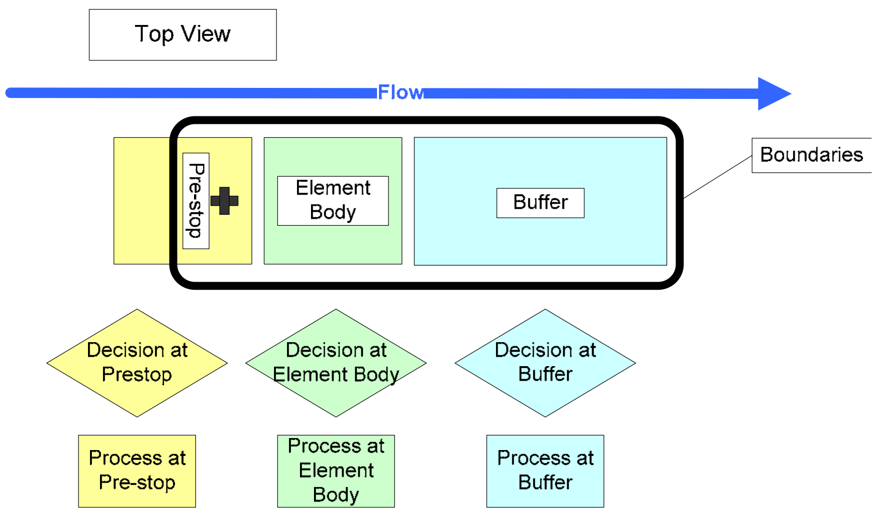


Figure E-6: Element and Flow Diagram Colour Coding

E.3 Real System and Simulation Logic

This section of the ASL presents the logic analysed from the Lion Assembly Line Case. The results from the analysis show that there are common logic patterns that allow the real system elements to be grouped together.

E.3.1 *Gap Section Conveyor*

Gap section logic incorporates a piece of conveyor that cannot hold a part and is used for transportation purposes only. The real system elements that fall into this category are:

Road Section

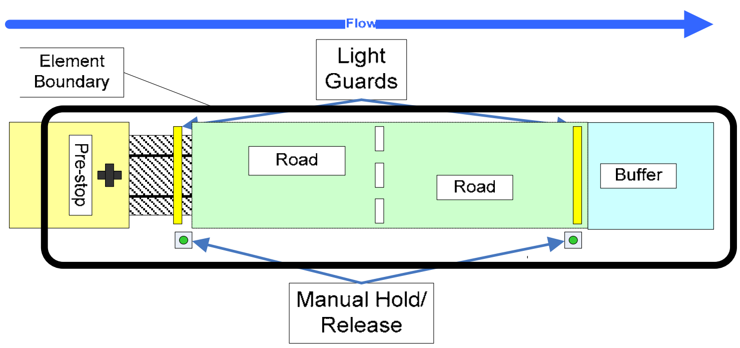


Figure E-7: Road Section Sketch

Orientator

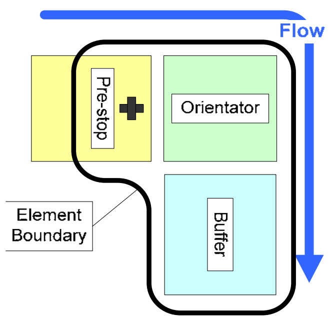


Figure E-8: Orientator Section Sketch

Walk Section

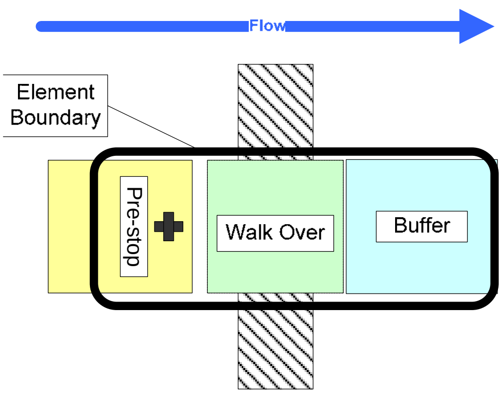


Figure E-9: Walk Section Sketch

Bend

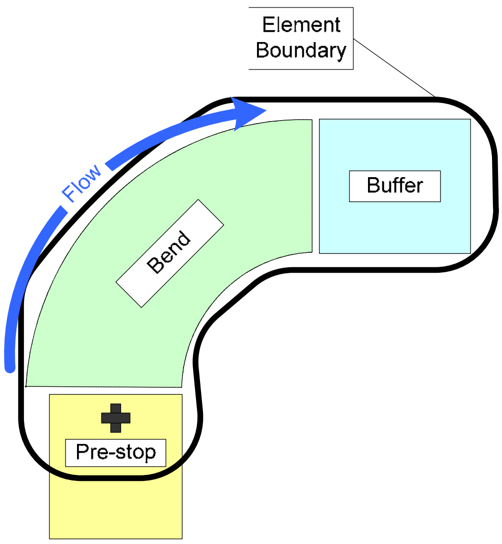
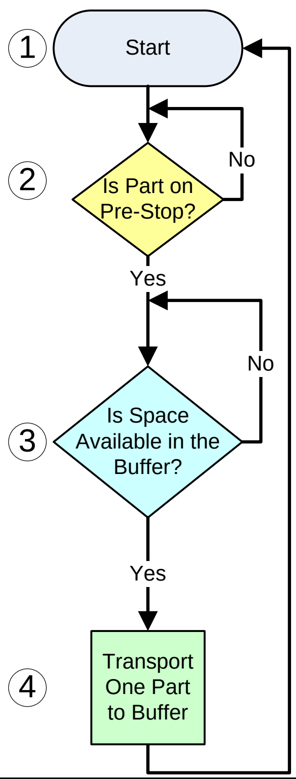


Figure E-10: Bend Section Sketch

E.3.1.1 Real System Logic Interpretation

Table E-4: Road Section Conveyor

<table>
<tr><th colspan="2">Flow Diagram for Gap Conveyor Logic</th></tr>
<tr><th>Diagram</th><th>Step Description</th></tr>
<tr><td rowspan="4">
</td><td>1. Starting position is select when the element is reset and ready to load part from the Pre-stop.</td></tr>
<tr><td>2. To advance to the next stage of the element a part must be present at the Pre-stop. If not the Gap Section will wait.</td></tr>
<tr><td>3. To advance to the next stage of the Gap Section process there must be space at the exit Buffer as the conveyor section of the Gap does not hold a part. The Pre-stop will not release until this is true.</td></tr>
<tr><td>4. The part is transported across the Gap to the next vacant position of the Buffer.</td></tr>
<tr><th colspan="2">Comments</th></tr>
<tr><td>Breakdown</td><td>A Breakdown on the Gap section will stop the moving conveyors on pieces of automation in the Zone.</td></tr>
<tr><td>Specific Comment</td><td><u>Road Section</u>
Have manual stop buttons that are designed to be used for material handling so that the trolleys can take parts to the correct place on the line. This is however not done as they wait for parts to cross the road.
The conveyor in this part of the line is at the same level as the floor.
The road section has light guards which tell when the part is in transit.
There is always a Pre-stop before road section.
<u>Walk Over</u>
The walk over is used for people to cross the line.
There is no manual stop to hold the part as the Gap is small.
<u>Bend</u>
The Bend is used to take the parts around the end of the line to change the direction of the flow of the line.
There is no manual stop to hold the part.
<u>Orientator</u>
An Orientator rotates the platen in relation to the conveyor. An Orientator can also change its direction.</td></tr>
</table>

E.3.2 *Turntable, Elevator & Lowerator*

A Turntable changes the direction of a part; the orientation of the part could be also changed. Usually a turntable is at a corner of the line.

An Elevator transports part vertically; it enables a part to go from one conveyor to a higher conveyor.

A Lowerator transports part vertically; it enables a part to go from one conveyor to a lower conveyor.

The logic of these elements have the same structure, the next flow diagram illustrate this logic.

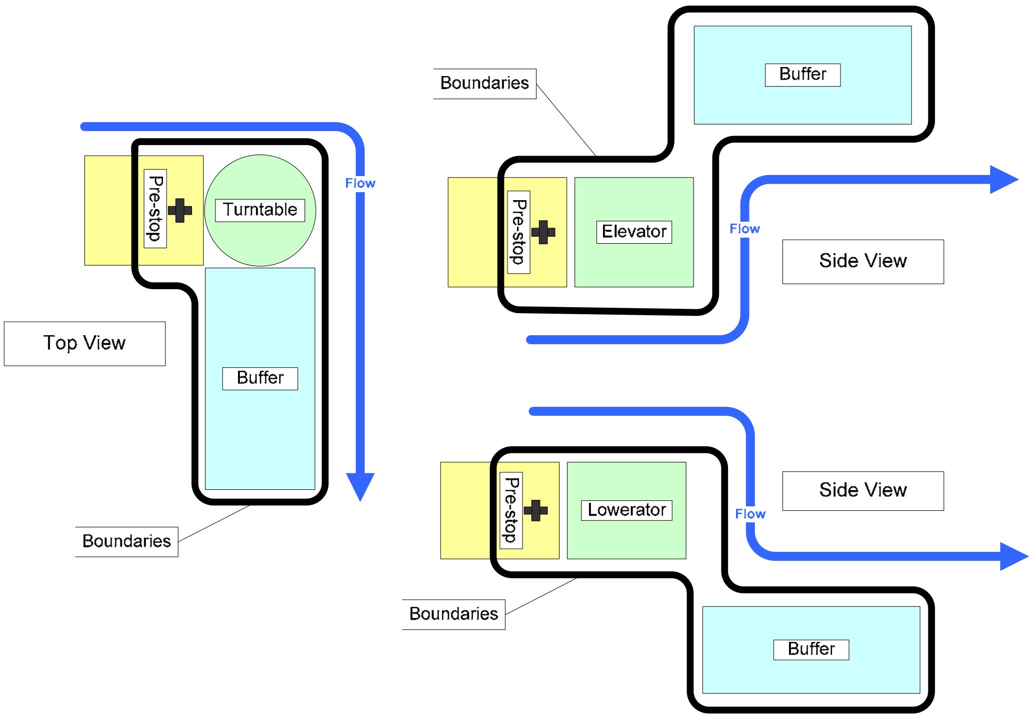
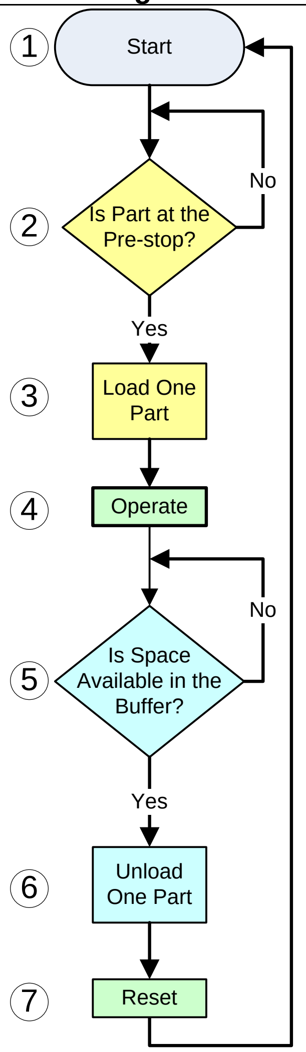


Figure E-11: Sketch of Turntable, Elevator & Lowerator

Figure E-11 presents a simple drawing of these elements. In green is the element itself, in yellow is where parts arrive (Pre-stop) and in the Buffer is in blue. The capacity of the Buffer depends on each situation. The diagram has the same colour code.

E.3.2.1 Real System Logic Interpretation

Table E-5: Flow Diagram for Turntable, Elevator & Lowerator

Flow Diagram for Turntable, Elevator & Lowerator	
Diagram	**Description**
	**1.** Starting position is select when the element is reset and ready to load part.
	2. If no part is at the Pre-stop the flow will stay in the loop until a part arrives at the Pre-stop. When a part is at the Pre-stop the element goes to next process.
	3. Load one part is a process. How it is loaded is not describe at the level of logic. How is loaded could be different for a turntable or for an elevator.
	4. Operate could be: Rotate (for Turntable), Elevate (for Elevator) or Lower (for Lowerator)
	5. This is the second decision point. Before unloading a part the element checks if there is a space in the Buffer. If there is no space the flow will stay in the loop until there is a space. When there is a space the element goes to next process.
	6. Unload one part is a process. How it is unloaded is not describe at this level of logic. How it unloads could be different for a turntable or for an elevator.
	7. Reset could be: Rotate back (for Turntable), Lower (for Elevator) or Elevate (for Lowerator).
Comments	
Breakdowns	A Breakdown on this will stop the moving conveyors on pieces of automation in the Zone.

E.3.3 *Divert*

A Divert changes the routes of parts dependant on an input signal from the control and quality systems. The direction of a part and its orientation can be changed. A divert is present when there are a number of possible direction for a part to be sent. Diverts are commonly present after automated test machines and where there is a choice of more than one operation to perform processes on the part. Figure E-12 shows the sketch for a typical divert after an automated test machine where the second option of part flow is to or from a rejection/injection spur.

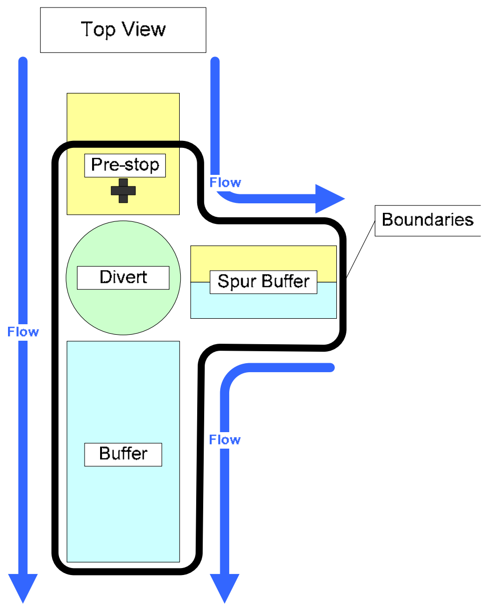


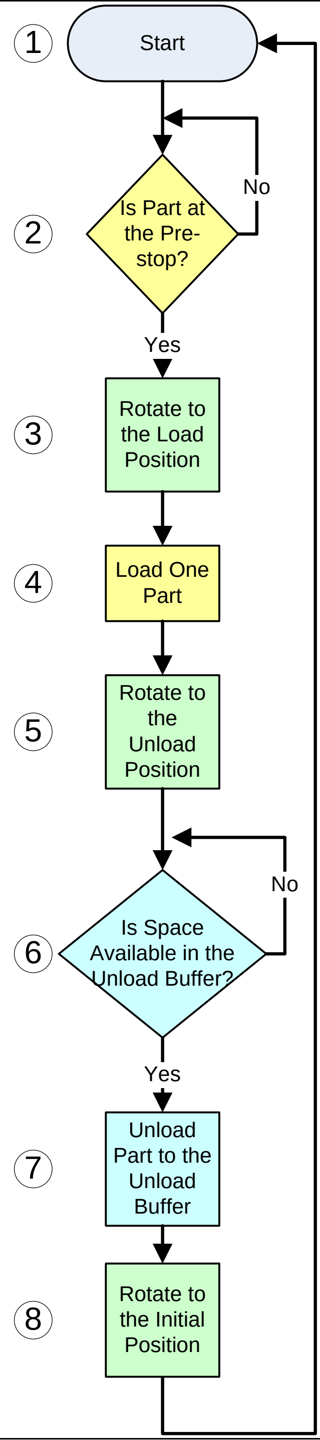
Figure E-12: Divert Sketch

E.3.3.1 Real System Logic Interpretation

Table E-6: Divert Logic

Flow Diagram for Divert

Diagram



Description
1. Starting position is selected when the Divert is reset and ready to load part from the Pre-stop. Several Pre-stop could be present. The reset position depends of each Divert (each situation).
2. The Divert prioritises one Pre-stop or could work as “first come first served”, here again it depends of each situation.
3. According to which Pre-stop the part is at, the Divert could rotate to this Pre-stop. If it is at the Pre-stop of the reset position the Divert does not need to rotate.
4. The Divert loads one part from the selected Pre-stop.
5. The unload position depends on the nature of the part (rejected or injected) or which Pre-stop the part is from. Again this depends of each situation. The Rotation could be different or some times unnecessary to “go” to the unload position.
6. Before unloading a part the Divert checks if there is a space in the selected Buffer. If there is no space the flow will stay in the loop until there is a space. When there is a space the Divert goes to next process.
7. Once the Divert is in the right position to unload, it unloads one part.
8. The Divert rotates to its initial position. This rotation will depend on the situation. It will depend in which position the Diverts was to unload comparing it to the initial position. It could happen that no rotation is required.

Table E-7: Divert Logic Comments

Comments	
Breakdowns	A Breakdown of a Divert will stop the moving conveyors on pieces of automation in the Zone.
Specific comment	The external input to know if the part must be rejected or not comes from the control system. To know if a part has to be injected that also the control system which provide the information.

E.3.3.2 Gaps between Simulation Logic and Reality

Table E-8: Real System and Simulation Logic Gap Observation for Divert

Simulation logic	Gaps
In the simulation a Divert is modelled with the same logic. The difference is only on the Cycle Time. Different Cycle Times are used for the different scenario. Load and unload part take the same time but the number of rotations make the Cycle Time different. If rotations are necessary to turn to the loading and the unloading area the Cycle Time will be longer.	No gap, but different types of Divert exist on the lines. The rotations are different in each situation so the Cycle Times are different. Diverts follow one logic but with different Cycle Time.
In the simulation model the element could load and unload part at the same moment.	In the reality this is not possible the Element need to reset. This gap is very small since the reset action does not take a significant amount of time.

E.3.4 *Manual & Auto Operation*

An operation that involves a man and tools can be called a manual operation.

The operator has work content that must be finished within a pre-defined time. If the operator goes over this pre-defined time then they push a button to release it. If it doesn't release then a repair or some other process is required in order to pass the part as good quality. If there are any problems that occur in an operation (manual, semi or automatic) the quality system is written to via an Antenna. If a manual operation finishes before the designated time the part will not release until the end of the cycle.

An Automatic operation carries out all the above part flow functions without manual intervention.

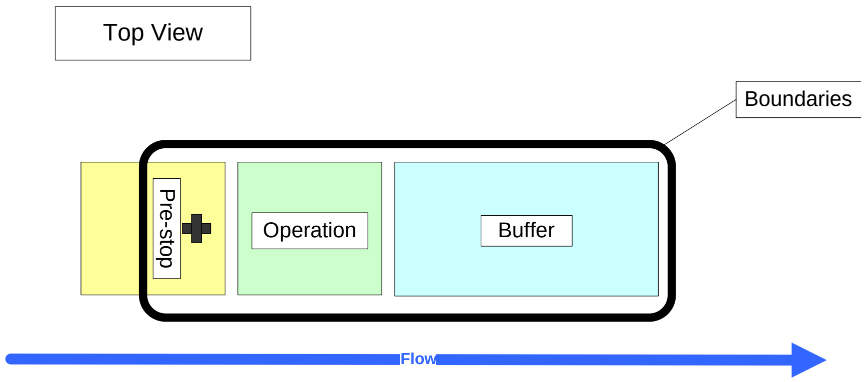
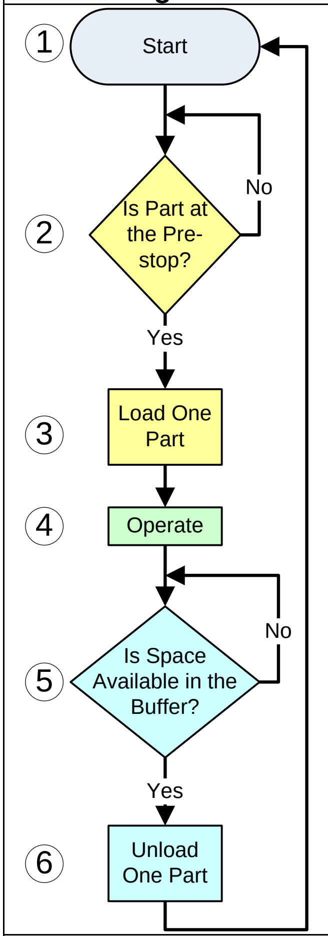


Figure E-13: Manual & Auto Operation Drawing

E.3.4.1 Real System Logic Interpretation

Table E-9: Manual & Auto Operation

<table>
<tr><th colspan="2">Flow Diagram for Manual and Auto Operation</th></tr>
<tr><th>Diagram</th><th>Description</th></tr>
<tr><td rowspan="6">
</td><td>1. Starting position is select when the element is reset and ready to load part from the Pre-stop.</td></tr>
<tr><td>2. If no part is at the Pre-stop the flow stays in the loop. If a part is at the Pre-stop the Operation goes to next process.</td></tr>
<tr><td>3. The Operation loads one part</td></tr>
<tr><td>4. The Operation processes the part.</td></tr>
<tr><td>5. Before unloading a part the element checks if there is space in the Buffer. If there is no space the flow will stay in the loop until there is a space. When there is space the element goes to next process.</td></tr>
<tr><td>6. The Operation unloads one part.</td></tr>
<tr><th colspan="2">Comments</th></tr>
<tr><td>Breakdowns</td><td>In case of Breakdown for one step of the Operation all the Operation stops.
Breakdowns call a team leader for assessment.</td></tr>
<tr><td>Specific comment</td><td>In case of Manual Operation, a button must be pressed manual to finish the Operation</td></tr>
</table>

E.3.5 *Transfer Machine*

Transfer machine has the characteristic to load and unload almost simultaneously. There is always a part in this machine, during normal automatic operation. Transfer Operation can contain several parts. Transfer Operations can have several sub-operations performed on a part in series. The Pres-stop is located at the first Sub-operation and the Buffer after the last sub-operation. Between sub-operations buffer are possible but they are include in the Transfer Operation capacity.

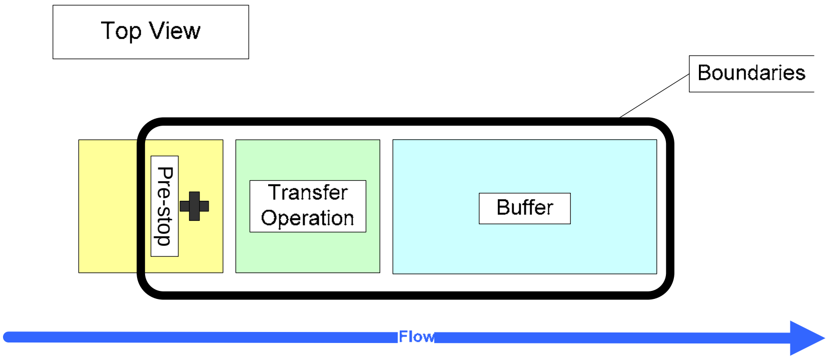
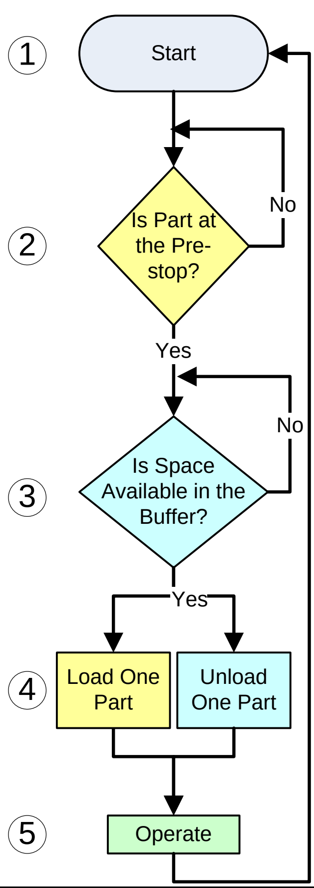


Figure E-14: Transfer Operation Drawing

E.3.5.1 Real System Logic Interpretation

Figure E-15: Transfer Operation

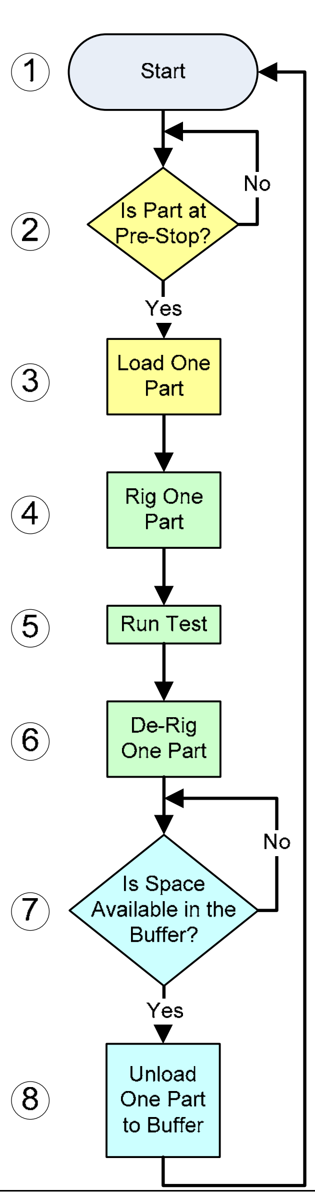
<table>
<tr><th colspan="2">Flow Diagram for Transfer Operation</th></tr>
<tr><th>Diagram</th><th>Description</th></tr>
<tr><td rowspan="5">
</td><td>1. Initial Conditions: Transfer Operation is reset and ready to load part from the Pre-stop.</td></tr>
<tr><td>2. If no part is at the Pre-stop the flow stays into the loop. If a part is at the Pre-stop the Transfer Operation goes to next process.</td></tr>
<tr><td>3. Before unloading a part the Transfer Operation checks if there is space in the Buffer. If there is no space the flow will stay in the loop until there is a space. When there is space the Transfer Operation goes to next process.</td></tr>
<tr><td>4. The Transfer Operation loads and unloads parts at the same time.</td></tr>
<tr><td>5. The Transfer Operation processes the part or parts. Several operation sequences could be included in an operation with a part capacity >1.</td></tr>
<tr><th colspan="2">Comments</th></tr>
<tr><td>Breakdowns</td><td>In case of Breakdown for one step or one Sub-operation of the Transfer Operation all the Transfer Operation is blocked, but other steps or Sub-operation finish there cycle.</td></tr>
<tr><td>Specific comment</td><td>Generally, parts are loaded / unloaded one by one but it could be two by two or more.
The operation could contain more than one part.
The Transfer Operation could be manually emptied by an operator.</td></tr>
</table>

E.3.6 *Semi-Automatic Operation (Test Bays)*

A Semi Automatic Operation has a man and a machine. The person carries out their work content then the machine takes over the rest, freeing up an operator to do something else.

E.3.6.1 Real System Logic Interpretation

Table E-10: Real System Logic for Test Bays



Flow Diagram for Hot and Cold Test Bays	
Diagram	**Step Description**
1	**1.** Starting position is select when the Semi-Auto Operation is reset and ready to load part from the Pre-stop. The previous Operation has finished and there is no part present.
2	**2.** To advance to the next stage of the element a part must be present at the Pre-stop. If not the Test Bay remains idle.
3	**3.** If the part is at the Pre-stop it is loaded into Test Bay.
4	**4.** The test equipment is mounted onto the engine by a Person.
5	**5.** The automated test operation is performed.
6	**6.** The test equipment is removed from the engine by a person.
7	**7.** To unload the test bay there must be free space in the Buffer.
8	**8.** If there is space in the Buffer, the part is released.

Table E-11: Comments on Test Bay Logic

Comments	
Breakdown	A Breakdown on the Semi-Auto Operation only affects the operation concerned.
Specific comments	Information is uploaded onto the quality system and also onto the platen to record the test results. If an engine fails during test it can be taken out of the line for repair of re-work and then re-tested. <u>Cold Test</u> The cold test is performed in-line. The engines are 100% tested. <u>Hot Test</u> The hot test is performed off line. The engines are sampled out of the line to test them.

E.3.7 *Continuously Moving Line (CML)*

A CML consist of a number of manual operations and a conveyor that does not stop at each operation. The pitch distance gives the operator enough space and time to complete the cycle in the index time.

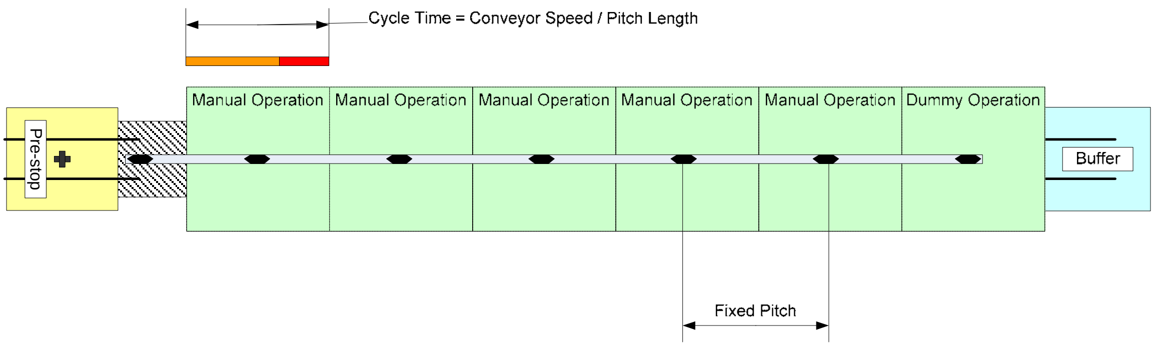


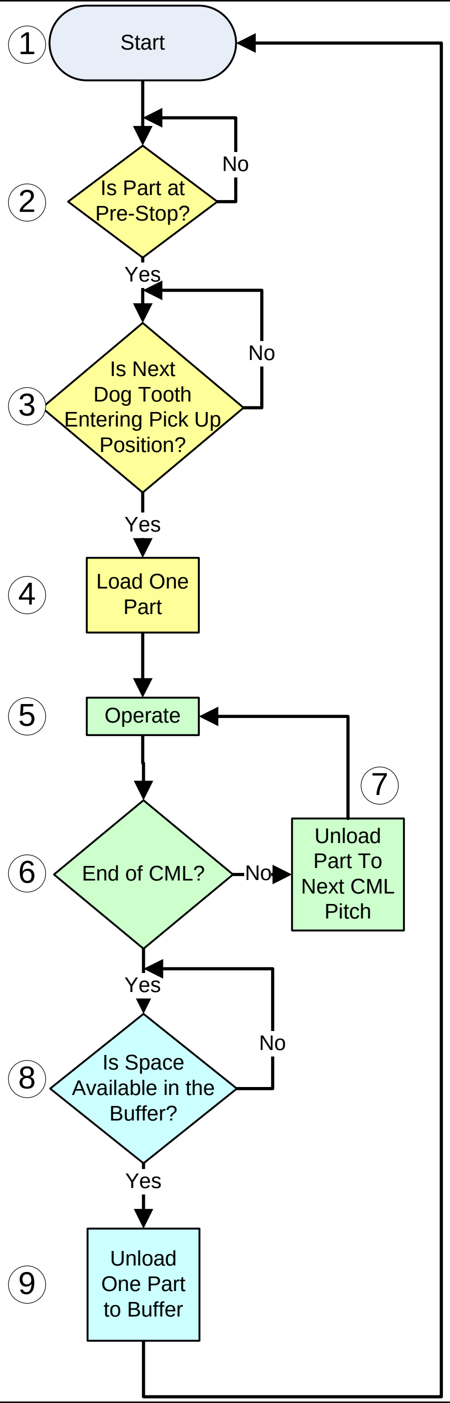
Figure E-16: Diagram of CML

E.3.7.1 Real System Logic Interpretation

Table E-12: Real System Logic for CML

Flow Diagram for CML

Diagram



Step Description	
1. Starting position is when the CML is reset and ready to load part from the Pre-stop.	
2. To advance to the next stage of the element a part must be present at the Pre-stop. If not the operator will wait.	
3. A part can only be loaded onto the CML when the dog tooth picks up on the base of the platen. If the dog tooth is not approaching the correct position the part will remain on the Pre-stop.	
4. The part is released from the Pre-stop to join dog tooth.	
5. A manual operation is carried out with a CT	
6. The presence of another operation determines a parts next process.	**7.** If there is another operation the Cycle Time starts again as the part enters the next pitch.
8. To unload the final operation there must be free space in the Buffer. If not the whole CML is blocked.	
9. The part is unloaded from the final operation to the Buffer.	

Table E-13: Comments on Test Bay

Comments	
Nature of Buffer	The Buffer of this element is a multi or single part forward conveyor. The Buffer conveyor is at the standard speed not reduced CML speed. There is an Antenna with a Stop at the end of a CML where the part is held while the information is updated with the quality system.
Breakdown	Breakdown times are based on the conveyor chain and dog tooth. This could be different from the Breakdown of the conveyor as different components are used. There are no Breakdown failures associated with the men. An operation must be completed before a break.
Specific comment	The dog teeth are a fixed distance apart equal to the length of a pitch. The pitch distance where the operation is carried out over and the conveyor speed is equal to the index time for a part to move through a standard operation. The spaces between the platens on the CML are controlled by the spacing of the dog teeth. If a platen is late arriving at the CML then the dog tooth will miss the platen. If one operation goes over cycle the complete CML will stop. A gap can travel through the CML. One part does not have to arrive to enable one part to leave.

E.4 General Cases and Specific Observations

In this section issues that have been observed on the Lion Assembly Line are presented. The specific observations relating to the individual lines are also shown.

E.4.1 *General Logic Issues*

This section describes the observations and factors that apply to both lines.

E.4.1.1 Breakdowns

When a Breakdown situation occurs, the scenario followed is generally the same:

1. The operating system establishes a diagnostic and sends it to the control system and calls operator.
2. If the operator cannot fix the Breakdown within 10 minutes, the operator has to call maintenance.

E.4.1.2 Antenna

<u>Real Life</u>

The RFID Antenna is used to read and write information on to an RFID tag in the base of the platen. The tag holds information about the type of Part that is mounted on the platen. The information contained on this tag can be used automatically by a machine to set itself up ready for the platen arriving, for example.

The Antenna puts information into the quality system.

A Breakdown an Antenna system stops the assembly line. The Breakdown may prevent information transfer to the quality system and could potentially change the sequencing of the parts.

The Antennas determine what path and operations are carried out on a part.

The Antennas are not mentioned in the work standard.

E.4.1.3 Frequency Event

A frequency event happens every x number of cycles. This can be built into the simulation model and depends on the element and the work content at that element. An example of a frequency event is when an operator brings a consignment of components to an operation when the proceeding consignment empties.

E.4.2 *Specific Issues from LAL Analysis*

This section describes some specific issues related to the Lion Assembly Line, based on observed scenarios.

E.4.2.1 Line Transfer

A line transfer is used in the Assembly Line to introduce a component to be assembled onto the engine. The component could be the cylinder head, kitting box or pistons.

<u>Gantry</u>

The Gantry on the Lion Line is used as an overhead conveyor to take cylinder heads from the Cylinder Head Line to the main loop.

There is an entry point and an exit point on the Gantry.

The Gantry does not hold a part.

The Gantry picks up the correct part and places it in the exit Zone for the correct assembly operation based on the sequencing of the parts.

The Gantry is modelled as an operation that transfers parts from one line to another.

Breakdown of the Gantry could affect both lines. However manual a back up of the Gantry is available using trolleys and parts so that a Breakdown of the Gantry will not prevent the line from working. It will take team leaders away from other Breakdowns.

There is a short piece of conveyor present that transports the part that will join the main loop from the Buffer to the operation that carries out the operation.

Diagram

Use Figure E-17 in conjunction with the flow diagram in Table E-14.

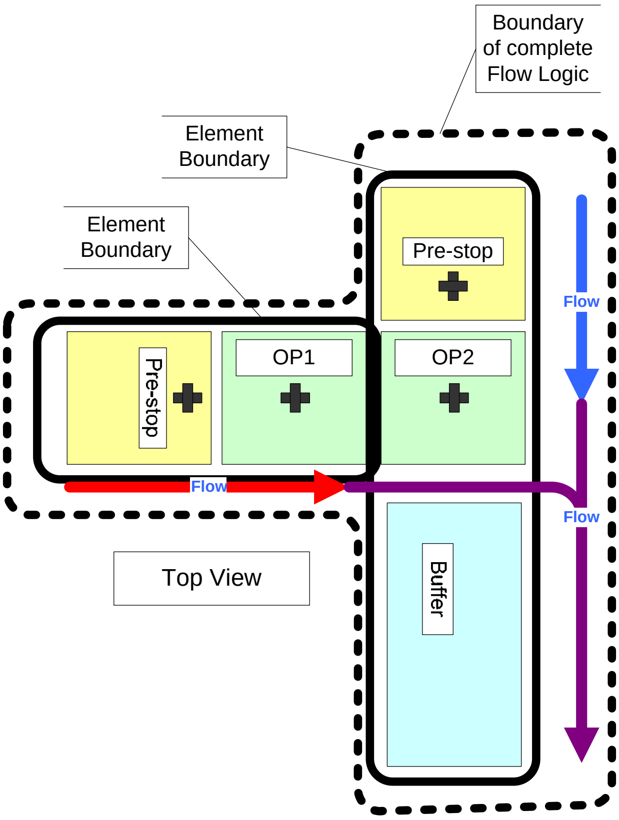


Figure E-17: General Diagram of Line Transfer

Table E-14: Real System Logic for Line Transfer

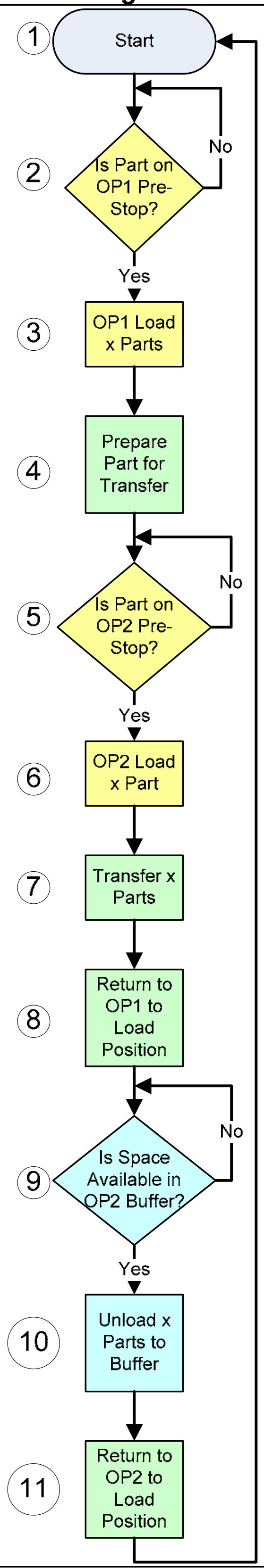
Flow Diagram for Line Transfer	
Diagram	**Step Description**
	**1.** Starting position is selected when both elements of each loop are re-set and no parts present in either Operation.
	2. To advance to the next stage of the Line Transfer a part must be present at the OP1 Pre-stop. If not OP1 will wait.
	3. If a part is present at the Pre-stop, OP1 loads the required number of parts.
	4. An action is carried out on the part to prepare it for transfer.
	5. To advance to the next stage of the transfer a part must be present at the OP2 Pre-stop. If not OP2 will wait.
	6. If a part is present at the Pre-stop, OP2 loads the required number of parts.
	7. Both operations have the parts in place so the transfer motion completes.
	8. OP1 returns to its load position.
	9. OP2 must check the unload Buffer for space.
	10. OP1 unloads the parts it contains to the Buffer.
	11. OP1 returns to its re-set (Load) position.

Table E-15: Comments of Line Transfer Logic

Comments	
Breakdown	A Breakdown of either operation can cause blockage to both lines. There are manual back ups possible for the systems to allow the lines to continue functioning.
Specific comment	The number of parts that are transferred depends on the operation. The number is fixed due to the nature of building the engine. The type of part transferred can change depending on the part derivative. Operation 1 and 2 can be Gantry's with a Cycle Time. The preparation is carried out and the transfer process is the same.

E.4.2.2 Assembly Line Manual Operation Special Case

When assembling the V6 engines, there is a manual operation that applies glue for the ladder frame (OP1, Figure E-18). There are special conditions within the operation due to the glue drying that means that the next operation must be finished within 10 minutes of the start of the preceding operation.

This is done with a person who waits until the next operation (OP2, Figure E-18) is free. This bypasses the Auto Op (OP2) Pre-stop as the machine is never busy when the manual op finishes. This causes the man to go over cycle frequently and also creates gaps in the line flow.

This problem only occurs on V6 as the V8 engines do not require the glue applying.

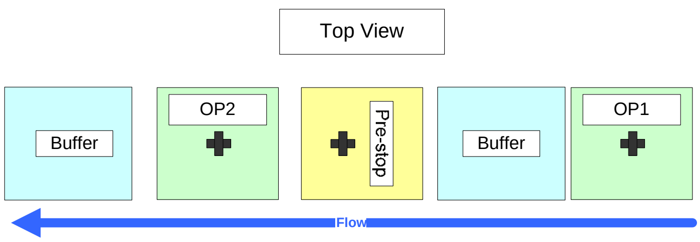


Figure E-18: Diagram of Manual OP1 and Auto OP2 Special Case

E.4.2.3 Part Quality Related Extractions and Insertions

A Quality extraction occurs when a Manual or Automatic Operation has a problem with the assembly of the engine and prevents the operation for being completed. The part is extracted and fixed off line as it requires more time to fix the part than the limit for an online fix.

- An Automatic Operation has three attempts to complete its cycle if there is a quality problem.
- The Cycle Time increases accordingly.
- The Operation calls a team leader to fix the problem online, inside the machine if possible.
- If the machine is closed the part will be rejected from the machine to the next available Buffer position to allow the part to be manually checked and re-inserted.
- There is a variation in the time between these two types of auto operation repair scenarios.

A Manual Operation will naturally have a few attempts to fix the problem before blocking the operation and calling for assistance.

<u>Common Extraction Issues</u>

In reality there could be a large number of operations between the Spurs. In this case the part will travel through the system, stopping at the operation pitch for the index time with no operation performed on it. The machine or Person will remain idle for the index time and hence there will be no Breakdown associated with the operation. This is communicated to the operation by the quality system from the platen RFID information stored.

<u>Common Reinsertion Issues</u>

The quality system is updated with the information about why the part came off the line and what was done to it. This is used to track the part through the system and inform operations what should or should not be carried out on the part.

Communication is important during re-insertion as the sequence of the line is changed and this is communicated to the manual operations that require sequencing information (See Section E.4.2.6 Marriage Point). The re-insertion of one Part does not occur regularly so sequencing issues are minimal with good communication.

There are 3 Levels of Quality issue where a part is extracted from the line and then returned to the line. This is explained below in the examples using Figure E-19, Figure E-20 and Figure E-21. In the examples the operation that causes a problem is OP2.

Level 1

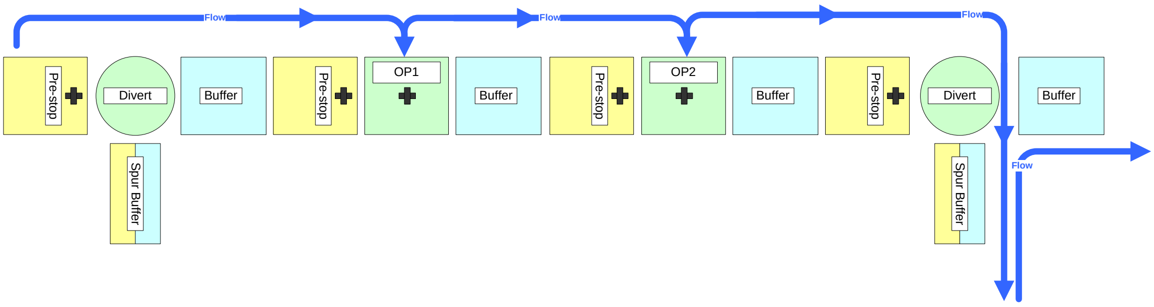


Figure E-19: Diagram of Level 1 Quality Issue

The problem caused by OP2 can be fixed off line and re-inserted where it came off without having to travel through the section again.

Level 2

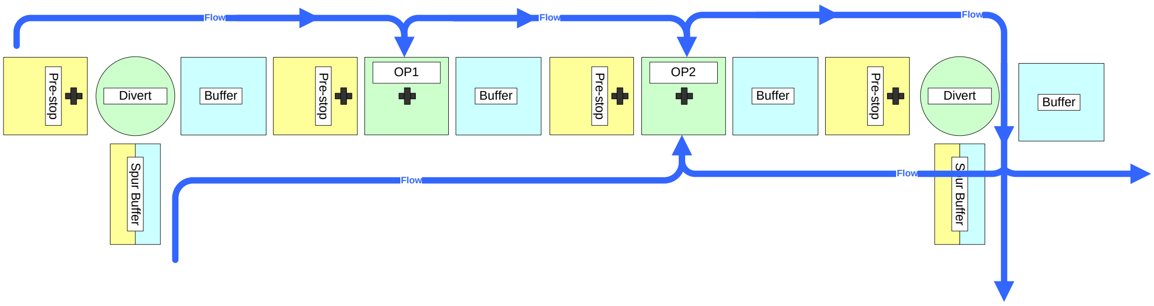


Figure E-20: Diagram of Level 2 Quality Issue

The quality issue caused by OP 2 is stripped back to the level it was at when it completed OP 1.

The part is re-inserted at the previous Spur and travels through OP1 without any operation being performed on it.

The part remains in the operation until the output buffer has a free space.

When a part is partially stripped back and is put back through the line it travels through the system, the Antennas have already communicated the sequence of the part through to operations and so unnecessary actions are not carried out on that part.

Human communication is also used to inform operators that there are parts with quality issues being re-inserted.

Level 3

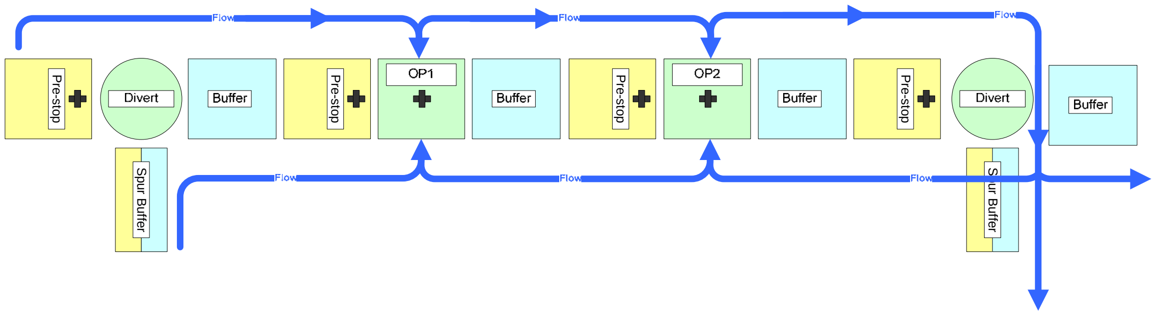


Figure E-21: Diagram of Level 3 Quality Issue

The quality issue caused by OP2 is major and requires a complete strip back to the level before the part entered the OP1.

The part is injected into the line to travel through all operations.

E.4.2.4 Automation Breakdown

The automation equipment:

- Conveyor (Buffer)
- Turntable
- Divert
- Bend
- Walkover
- Road Section
- Lower/Elevator

A Zone contains different types and numbers of automation equipment.

The automation equipment is linked using a control cabinet. The Zones are dictated by the content of the control cabinet. The more complex the complete control system for that Zone the less pieces of automation is included in the control cabinet. The Zone size is controlled by the number of I/O's available in the PLC.

A Breakdown in a piece of automation equipment will cause all automation equipment in the Zone to stop. It has no effect on the operations completing their cycle. However they may not be able to pass the part onto the Buffer.

A Breakdown in a Zone will cause a queue to form at the end limit of the preceding Zone and starve the automation and operations of the proceeding Zone.

The automation Zones are not linked to the Zones for the operator teams shown on the work standard.

E.4.2.5 Kitting Loop Operation

All kitting operations are manual operations that follow the same logic as Manual Operation. The operation must have 4 parts present to carry out operation.

E.4.2.6 Marriage Point

A marriage point is where the sequence of the parts is monitored and information given to the necessary sub assemblies and critical operations to prepare the necessary parts ready to accept a sequenced part. There are 5 Marriage points on the Lion Assembly Line:

Table E-16: Lion Marriage Point Locations

Location on LAL	Engine Marrying Components
Block and Platen Mating	Kitting Box
OP140	Cylinder Head
OP255	Ladder Frame Oil Pan
EA3-2230 Buffer Zone	Exhaust Manifold Turbo
EA4-2880 (Spur)	Wiring Harness

If there is a problem with these points the specific marrying components may not be sequenced correctly.

A platen can stay on a marriage point for up to 20 seconds, not including pitch traverse time. The Marriage points are located in specified Buffer Zone and affect the flow through the Buffer Zone.

E.4.2.7 Buffer Zone

Buffers are used to minimise the effects operations could have on the flow of the parts through the system if there is a problem with them.

The Buffers are sections of the line that contain elements that can hold a part e.g. Divert, single part conveyor or multipart conveyor.

The Buffers in real life contain a variety of elements have a Cycle Time that is not equal to the index time of an operation. This means that in the Buffer sections parts can ‘speed up’ allowing them to catch up with the next operation. This minimises the effect the removing poor quality parts or faulty operations has on the next elements. This is important particularly when manual operations are involved as the aim is to keep the person working as much as possible due to the expense of them.

E.4.2.8 Cylinder Head Loop

The Cylinder Heads are brought over from the machining line to the Lion line. On this line there are assembly operations performed on them. There are some assembly operations performed on them in the machining line.

The cylinder head loop can be run manually or automatically using the marriage sequencing points.

Manual operation is used to fill the Buffers up of a particular derivative before trying a different one.

There is a big Buffer after the last Antenna. This Antenna could say which lane it is to go in.

E.4.2.9 Lower/Elevator Operation

It is possible for a Lowerator or elevator to have an operation on it. The Cycle Time remains the same for the operation and the Lowerator. The Breakdowns should take into account the piece of automation and the operation characteristics.

The operation can be manual or automatic.

E.4.2.10 Road Section

<u>Road Section</u>

The stopping of a road section conveyor is modelled as a frequency event based on data from material handling systems. The Road section is modelled to be stopped when a material transportation goes across the line. This is not done in reality as the operators of the material transportation wait for a part to completely transport across the gap.

The frequency data can be omitted from this simulation element.

E.5 Conclusions

E.5.1 *Summary of Work*

The aim of this document was to allow a reader to understand the behaviour of components of the real systems to represent them accurately in a simulation model.

Section 2 is dedicated to presenting the relevant level of logic and the elements boundaries. The level of logic presented here was not the deepest level that was possible to represent. The level chosen is deep enough to match the real system element logic with the logic of the simulation elements.

In Section 3 each elemental component of the real system were studied using the selected boundaries and level of logic. When observing some apparently dissimilar elements (such as Turntable/Elevator or Bend/Road Section) the logic was analysed to find a common pattern.

In Section 4 the general issues relating to Ancillary Logic was presented. Special cases for the Assembly Lines have been shown and a comparison with the simulation and real logic has been presented.

E.5.2 *Difficulties Encountered*

The following difficulties and problems where encountered and solved:

- Defining a common vocabulary that relates to the simulation model and the real system.
- The identification of a common structure of the flow diagrams was an issue because what was observed in reality differed from case to case. The actions performed in reality by an element can differ but the underlying logic principles remain constant. The difficulty arises when translating these differences into common patterns of logic flow.
- It is less difficult to represent what occurs in real life in a textual description. However the length of the descriptions would make them indigestible. The diagrams are produced to lighten the text and make the explanation friendlier. The sketches with colour coding assist in conveying this message.

Overcoming these three important difficulties have enabled this document and the information contained in it to be communicated as simply as possible without loosing the message.

E.5.3 *Limits of the Specification Document*

This document is the first attempt of the specification of the Lion Assembly Line. There are therefore some inherent weaknesses and room for improvement:

- The framework of this document is in Word format which occupies a lot of pages. A more user friendly solution is obtainable using other frameworks such as an interactive Web based or PDF document with hyperlinks, videos and pictures
- It is possible that there are Ford logic components missing from this specification as a limited number of lines where observed. When people in the future use this document there may be gaps in the logic specified due to lack of total immersion in the real system.