O P T I M I S A T I O N O F M A N U F A C T U R I N G E X E C U T I O N S Y S T E M S U S I N G A S T A N D A R D S D E V E L O P E D R E F E R E N C E A R C H I T E C T U R E

Shashikant Jaichund Ramsangar

A research report submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, in fulfilment of the requirements for the degree of Master of Science in Engineering.

Johannesburg, 2012

DECLARATION

I declare that this research report is my own unaided work. It is being submitted to the degree of Master of Science in Engineering to the University of Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University.

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ABSTRACT

Competitive manufacturing enterprises seek to efficiently coordinate the manufacture and distribution of products and are therefore required to integrate plant and business systems. A key enabler of this aim is Information Technology (IT), specifically Manufacturing Execution systems (MES), which offers several benefits including increased operational efficiency. However, often existing MES don't integrate manufacturing processes and systems; also MES projects are sometimes unstructured and rely on heuristics for successful implementation. The informal approach to optimisation, results in a longer development time and often systems implemented are inefficient. Considering these issues, this research report has addressed the research question "How can Manufacturing Execution Systems (MES) be optimised using a reference architecture developed from standards?" The methodology used to answer this question consisted of an MES optimisation approach developed from authoritative sources. The approach consisted of an original MES reference architecture developed from relevant standards and key requirements of IT (Information Technology) frameworks. This approach was applied in a case study at Sasol, resulting in proposed improvements to manufacturing processes and MES technologies. Due to expected increases in operational and technology efficiency cost benefits were expected. Considering the challenges of existing MES and projects, this research report answered the research question, showing how MES can be optimised using a well defined reference architecture.

DEDICATION

This is dedicated to my family.

ACKNOWLEDGEMENTS

This author acknowledges Dr. Ionel Botef for esteemed guidance during this research and Sasol MES team and Steam Stations personnel for their valuable input and time.

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NOMENCLATURE

Acronym	Description
APC	Advance Process Control
APS	Advanced Planning and Scheduling System
BOD	Business Object Definitions
CDS	Chromatography Data System
CIM	Computer Integrated Manufacturing
CMM	Collaborative Manufacturing Model
CRM	Customer Relationship Management
DCS	Distributed Control System
EHS	Environmental Health and Safety
EPC	Event Driven Process Chain
ERP	Enterprise Resource Planning
FAD	Functional Allocation Diagram
ICS	Integrated Control System
IDEF 0	Integrated Computer-Aided Manufacturing Definition 0
IOM	Inventory Operations Management
ISA	Instrumentation, Systems and Automation Society
IT	Information Technology
KPI	Key Performance Indicator
LIMS	Laboratory Information Management System
LIS	Logistics Information System
MECHS	Mechatronic systems
MEMS	Micro Mechanical systems
MES	Manufacturing Execution System
MESA	Manufacturing Enterprise Solutions Association
MM	Materials Management
MMS	Maintenance Management System
MOM	Manufacturing Operations Management
MRP	Material Requirements Planning

Acronym	**Description**
OAGIS	Open Architecture Group Integration Standard
OLE	Object Linking and Embedding
OPC	OLE for Process Control
OS	Operating Systems
PIMS	Plant Information Management System
PLC	Programmable Logic Controller
PLM	Product Lifecycle Management
PM	Plant Maintenance
POM	Production Operations Management
PPSS	Production Planning Scheduling System
QOM	Quality Operations Management
SAP	Systems Applications and Products
SCADA	Supervisory Control and Data Acquisition
SCM	Supply Chain Management
SD	Sales and Distributions
SFC	Shop Floor Controller
SOP	Standard Operating Procedure
SPC	Statistical Process Control
SQC	Statistical Quality Control
SSM	Sales and Service Management
UML	Unified Modeling Language
WBF	World Batch Forum
XML	Extensible Mark-up Language

1. INTRODUCTION

This chapter provides a foundation for this research report. The subsequent section describes the background and justification of the research. Thereafter the research problem, question and hypothesis are presented. The research approach, methodologies and definitions are discussed. Then reference to key contributors is summarised and finally this research report is outlined.

1.1. Background of the Research

Information Technology (IT) is a key aspect of managing manufacturing enterprises. IT enables a company's subsystems to interface with each other and to coordinate the manufacture and distribution of product. Some of the key subsystems include supply chain, maintenance, production, health and safety, risk management and quality systems (Boucher and Yalcin, 2006). These manufacturing technologies are enabling manufacturing enterprises to evolve into cooperative information and knowledge-driven environments (Panetto and Molina, 2008). Therefore, during the last five decades manufacturing companies are using these advanced technologies as enabling solutions.

Considering the advancement of manufacturing technologies, one of the key concepts was Computer Integrated Manufacturing (CIM) (Nagalingam and Lin, 2008). Consequently, the concepts of interoperability and integration have become key requirements for manufacturing enterprises to remain competitive. Enterprise interoperability and integration is a domain of research developed since 1990s and is the extension of Computer Integrated Manufacturing concept (CIM) (Panetto, Molina 2008).

In this context, MES (Manufacturing Execution Systems) have been the technologies intended to bridge the communication gap between the plant floor and business systems (Morel et al, 2003, Boucher and Yalcin, 2006). Therefore, MES was considered a key technology that aimed to integrate the various sub system activities including those of design, production, maintenance, quality and supply management (Morel et al, 2003). Consequently, competitive MES vendors have been required to co-operate in order to promote high degrees of interoperability. For example, standardisation initiatives such as International Organisation for Standardisation (ISO) and Instrumentation and Systems and Automation Society (ISA) had already tried to promote such co-operation (Panetto, 2007).

Also, Chelmeta (2001) and Williams T.J. (1991) indicated that reference architectures should be used to guide design and implementation of integrated enterprise systems. Reference architecture development is required prior to system design (Cheng et al, 2001). Further to the architecture development, the manufacturing system design will continue with three phases. These are the conceptual, implementation and execution phases. The conceptual phase focuses on the logical design of functional and data requirements. The implementation phase involves the selection of the IT architecture such as database management system, hardware platforms and the communication medium. Finally, during the execution phase the concept models are coded in a software language.

Furthermore, standards such as the ISA S95 (ISA S95.00.01, 2000) and OAGIS (OAGIS, 2011) were used to guide reference architecture design and MES system optimisation. Consequently, these standards could solve the vertical interoperability and integration problem (Morel et al, 2003). Finally, enterprise systems were considered to be built on IT architecture defined as the technological foundation of computers, communications, data and basic systems (Liu, 2002). This IT architecture must enable interface connections between company's MES, the process control and Enterprise Resource Planning Systems (ERP) systems (Meyer et al, 2009).

1.2. Justification of the Research

From the research it is seen that manufacturing enterprises are seeking MES to address the challenges of integration and interoperability between plant floor and business system (Boucher and Yalcin, 2006, Morel et al, 2003). MES offer several benefits if designed, implemented and supported appropriately. These include integrated data transparency for decision making, reduction in time wastage, reduction in administration expenses, improved customer services, improved quality, early warning systems, real time cost control, increasing employee productivity and compliance with regulatory directives (Meyer et al, 2009).

However, MES projects are often unstructured, using heuristics from the past experience as a guideline for approach. This results in a longer development time and often the system is inefficient. To successfully gain economic benefit and to ensure that the benefits are achieved, reference architectures are required to guide the design of MES (Meyer et al, 2009, Chelmeta, 2001, Williams T.J., 1991). Therefore, reference architectures can shorten implementation times and support business process standardisation (Meyer et al, 2009).

1.3. Research Problem

Currently, MES are being deployed using heuristics; the hypothesis presented is that successful implementation requires the application of reference architecture based on standards. This will ensure that manufacturing processes are enabled using MES that are designed according to best practices with appropriate consideration of IT architecture. To solve this research problem, this research should address the question: "How can Manufacturing Execution Systems (MES) be optimised using a reference architecture developed from standards?"

1.4. Aims and Limitations

This research report aims to:

- develop an original MES reference architecture based on standards and key requirements of IT (Information Technology) architecture.
- apply the MES reference architecture in a selected case study at a Sasol Utility Plant.
- evaluate the MES reference architecture and approach based on experience from the case study.

Considering these aims, this research should have its own limitations:

- The scope will be limited to functional architectures or business processes. These business processes will represent a system or sub-system in terms of its structure and behaviour (Chen et al, 2008).

- Architectures aimed at structuring concepts and activities necessary to design and build a system are out of scope. However, the Integrated Computer-Aided Manufacturing Definition 0 (IDEF 0) methodology will be applied in functional architecture development (Boucher and Yalcin, 2006).
- The system design will focus on the conceptual phase and not on the implementation and execution phases of system design. However, IT architecture design considerations will be in scope.
- The scope of investigation will be limited to production, inventory, maintenance and quality manufacturing systems whereas supply chain systems are out of scope.

1.5. Research Question and Hypotheses

To address the research problem, key questions were posed to understand and solve the research issues. Chapter 2 discusses these questions in more detail however; key questions are how to:

- develop functional reference architecture from standards?
- apply the reference architecture to gain benefits of process standardisation and shorter implementation time?
- use the reference architecture and consider IT architecture to optimise MES and gain benefits?
- develop a formal MES optimisation approach?

1.6. Source of Data and Methodologies

This research report will follow an established methodology for functional architecture development, which is fundamentally based on business process re-engineering. Also, relevant MES standards will be used to develop reference architecture. This functional architecture will be captured in ARIS and will consist of processes and activities that describe the generic functions and data requirements of manufacturing plants.

Thereafter, the reference architecture will be applied at a manufacturing operation (Sasol Steam Stations) to understand how the MES are enabling the current production, inventory, maintenance and quality activities. The application will involve an in depth study of business activities and data collection will be carried out using one on one interviews, workshops and review of relevant operational documentation. The business models in ARIS will be used to identify the current maturity of MES and opportunities for system optimisation. An analysis will then be done to understand the current technology landscape, to understand how the Steam Stations (SS) can achieve the business objectives by leveraging existing IT assets.

The last phase will summarise the results of the analysis. Should the hypotheses developed during the research report be accepted; then the developed reference architecture and toolset will be reused to optimise comparable manufacturing operations. If the hypothesis is rejected, then appropriate reasons should be presented and a future study proposed.

1.7. Contribution

The contributions are shown Figure 1-1 below and will be discussed in Chapter 5.

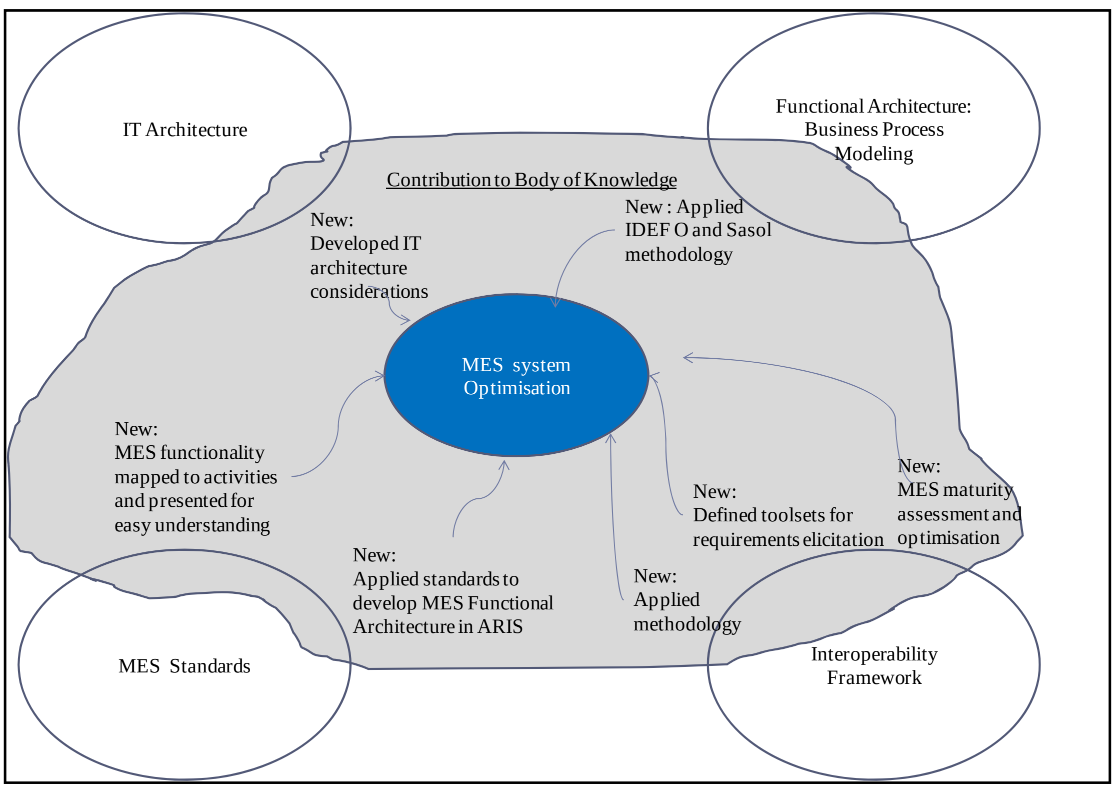

Figure 1-1: Contribution to Body of Knowledge

1.8. Definitions

In this section, important terms are defined as referenced from literature. James et al (2005) have defined Computer Integrated Manufacturing as “the integration of the total manufacturing enterprise through the use of integrated systems and data communications coupled with new managerial philosophies that improve organisation and personnel efficiency.”

Interoperability is typically defined as “the ability of two or more systems or components to exchange and use information” (IEEE STD 610.12, 1990). The ISO 16100 standard defines the manufacturing software interoperability as “the ability to share and exchange information using common syntax and semantics to meet an application-specific functional relationship through the use of a common interface” (Panetto, 2007). System integration occurs when smaller pieces of software are brought together to form a larger piece of software that was designed to solve a problem. Interoperability is a means to achieve integration (Panetto 2007).

During the 1980s and 1990’s the term Manufacturing Execution Systems (MES) described the set of manufacturing applications which enables manufacturing by integrating planning and control functions with execution functions (ARC, 2003).

1.9. Outline of the Research Report

The research report is composed of five chapters. Each chapter is composed of an introductory and concluding section. Chapter 1 provides a foundation for the research report by introducing key findings from literature and also justification and clear statement of the problem. Chapter 2 provides key insights into the research issues and research gaps. Chapter 3 describes the methodology used in this research report. Chapter 4 describes the research findings and discusses these in consideration of the research issues in Chapter 2. Chapter 5 considers the research problem and presents the conclusions and implications of this research from results discussed in Chapter 4.

1.10. Conclusions

This chapter has provided a clear statement of the problem being investigated and therefore the aims of this research report. Considering preceding literature, a justification for this research has been discussed. Research methods and sources of data were discussed, followed by a description of contributions and definitions. A preview of the remainder of the research report has been presented to ensure that the reader is able to understand the relationship between different chapters. Based on this introductory chapter, this research report can now continue to describe the research in more detail.

2. RESEARCH ISSUES

2.1. Introduction

This chapter identifies research issues regarding the problem being investigated and aims to discuss these considering the relevant body of knowledge. Figure 2-1 shows the layout of the chapter.

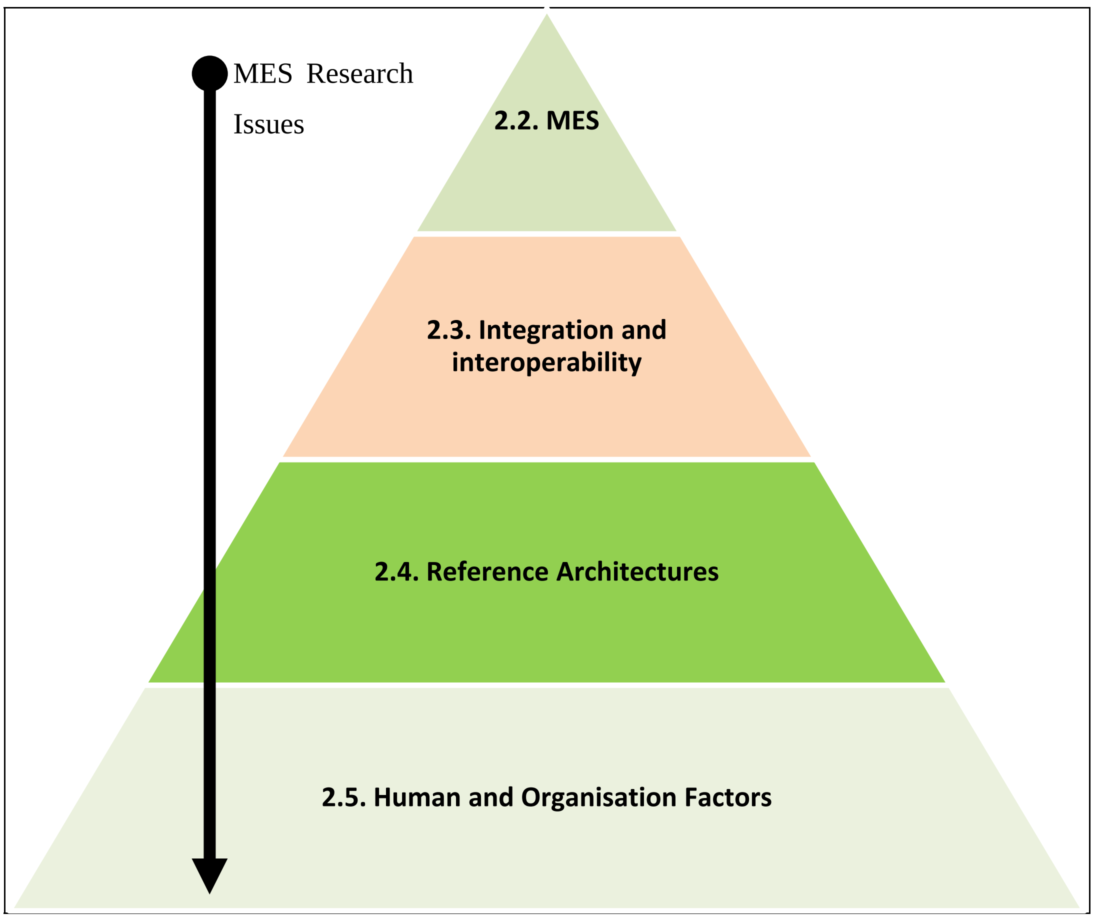

Figure 2-1: MES Research Issues

2.2. Manufacturing Execution Systems

In the late 1970s, Material Requirements Planning (MRP) was one of the first attempts for an Enterprise Resource Planning (ERP) type system to close the loop between planning systems and execution systems. In MRP systems a master production schedule is derived from sales orders and product replenishment targets. Subsequently, MRP type 2 systems were used to derive master production schedules; however in this case resource capacity was also considered in the development of the master schedule (Boucher and Yalcin, 2006).

Considering these attempts, existing ERP systems are largely focused on achieving planning, accounting and administrative functions (Meyer et al, 2009). These systems are generally perceived as being planning systems and are not well integrated into the execution of production. Therefore in the 1980’s and 1990s, MES have been introduced to integrate the production planning systems with the lower layer execution systems (Bo and Zhenghang, 2004, Boucher and Yalcin, 2006, Meyer et al, 2009). Since then, MES have developed to integrate manufacturing activities such as production, maintenance, quality and supply management activities over the product life cycle. Therefore, MES serve as an integrated system to enable previously standalone or patchwork systems. If MES are designed correctly, the integration platform allows for the modular use of individual functions and also exposes these functions so that they are able to interoperate with other software systems (Meyer et al, 2009). Also, operations personnel will be allowed better data visibility by interfacing planning and execution functions.

However, enterprise integration type projects are often unstructured and mainly rely on heuristics to guide design. Therefore, reference architectures are required to guide the design of integration projects (Chelmeta, 2001, Williams T.J., 1991). The reference architectures will introduce reusable design constituents such as functional requirements and IT architecture considerations (Meyer et al, 2009, Chelmeta, 2001, Williams T.J., 1991).

All these have motivated the problem being addressed in this research and leading to the research question, **“How can Manufacturing Execution Systems (MES) be optimised using a reference architecture developed from standards?”** The following sections of this chapter will discuss key issues used to address this research problem.

2.3. Integration and Interoperability

Enterprise integration ensures that there is interaction between sub systems so that a common objective is achieved. Enterprise integration can be at a functional level (via business processes), application level (via software systems), or hardware level (via computer networks) (Chen, D. et al, 2008). Integration is achieved by interoperability, where interoperability is the ability for two systems to understand one another and to use functionality of one another (Panetto, H. 2007).

Considering the interaction between sub systems, the Collaborative Manufacturing Model (CMM) has proven a useful concept for suppliers and manufacturers to achieve interoperability. Figure 2-2 shows the enterprise domain where business functions lie above the central plane and production functions below (Gorbach, 2004). A collaborative manufacturing network can be modeled as spheres or manufacturing nodes connected by material, information and process flows. The nodal spheres encompass three axes enterprise, value chain as well as product and asset lifecycle (Gorbach, 2004).

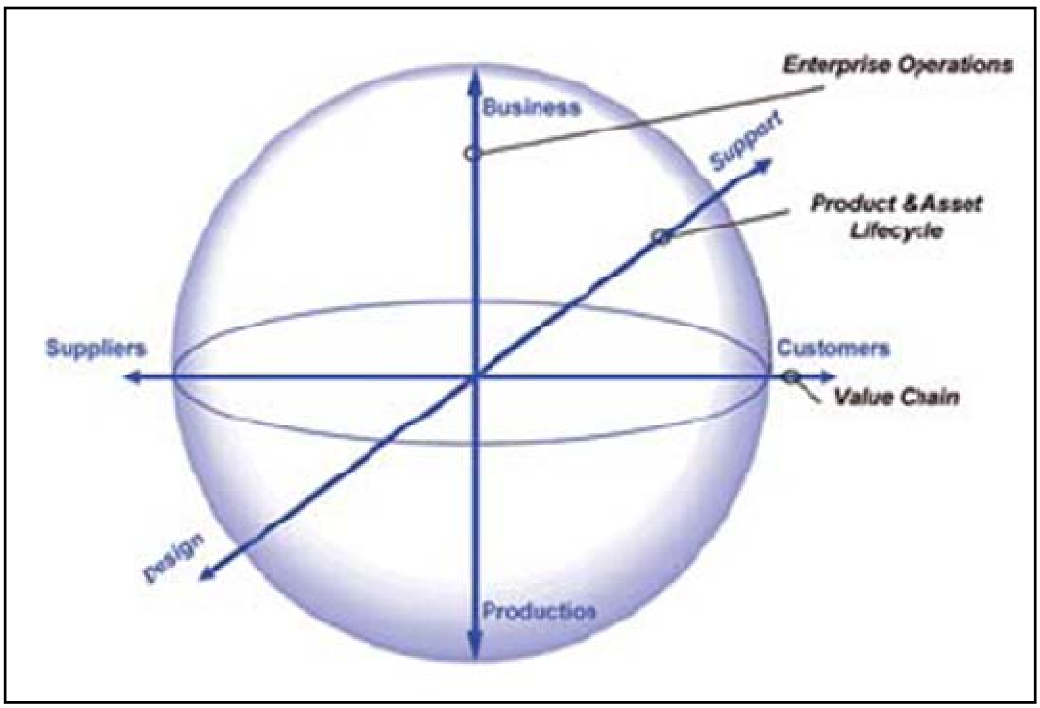

Figure 2-2: Three dimensional model of CMM node (Gorbach, 2004)

Considering the enterprise domain representation, manufacturing enterprises deploy a host of advanced manufacturing technologies to enable the plant to business systems integration. Table 2-1 shows the list of technology that is available from IT vendors (Morel et al 2007, Nagalingam and Lin 2008).

Table 2-1: Plant to Business Systems (Morel et al, 2007, Nagalingam and Lin 2008)

#	Software Application	Functionality
1	CRM	Customer relationship management
2	SSM	Sales services management
3	SCM	Supply chain management
4	ERP	Enterprise resources planning systems are the advancement of MRP type 2 software which describes a suite software applications integrated to serve and support multiple business functions.
5	MES	Represents a new and practical approach to link information with action on the shop floor to help the managers in improving quality, response and profitability in the operation.
6	APS	Advanced Planning and Scheduling Systems
7	MECHS	Mechatronic systems
8	MEMS	Micro mechanical systems
9	AUTO ID	Automatic identification
10	E-commerce related applications	E-business, web-enabled, E-procurement, E-fulfilment and others.
11	SFC	Shop Floor Controllers
12	DCS	Distributed Control System
13	PLC	Programmable Logic Controllers
14	SCADA	Supervisory Control and Data Acquisition

The introduction of these manufacturing technologies has increased the complexity of choosing functionally and technologically acceptable systems, which interoperate with an organisations existing technology landscape. Competitive vendors are therefore required to co-operate or use MES standards to promote high degrees of interoperability. This is required in order to provide a solution that meets the demands of the customers. Standardisation initiatives, supported by standardisation bodies have assisted this problem (Panetto, 2007, Gorbach, 2004, Meyer et al, 2009).

Considering the challenges in enterprise integration, a key prerequisite to guide plant and business systems integration is the development of functional reference architecture to coordinate design and implementation the enabling information systems (Williams, 2991, Gorbach 2004, Boucher and Yalcin, 2006 and Meyer et al, 2009).

This leads to the 1st hypothesis: **"MES enable integration and interoperability between plant and business systems however, functional reference architecture is required to guide MES optimisation"**

2.4. Reference Architectures

Since the 1970s and 1980s standards have been developed to meet the enterprise integration challenge (Meyer et al, 2009 and Chen et al, 2008). The organisations responsible for driving standardisation have been the CEN (European Committee of Standardization), ISO (International Standardization Organization), IEC (International Electro-technical Committee), ISA (Instrumentation, Systems and Automation Society) and IEEE (Institute of Electrical and Electronics Engineers) (Chen et al, 2008). Non profit organisations such as OMG (Object Management Group) and OAG (Open Applications Group) have also contributed to this domain (Chen et al, 2008).

Considering these initiatives standards can be categorised as follows (Chen et al, 2008 and Liu, 2002):

- Type (1): Standards relevant to enterprise modeling and engineering.
- Type (2): Standards relevant to functional and information architectures relating to systems representation.

- Type (3): Standards and guidelines relating to enterprise IT services and infrastructure.

However, gaps exist for the development of type (2) or Functional Architectures and type (3) or IT Architectures and these are required to guide the definition of manufacturing enterprise structure and operation. MES projects are often unstructured and therefore reference architectures are required to guide implementation (Chapter 1.2). Therefore, this research report will focus on reference architectures so that they are applied formally to describe and guide system implementation.

The ISA S95 model: In 1991 the ISO TC 184 SC5/WG1 also known as the Purdue Reference Model for Shop Floor Production Standards was one of the earliest standards proposed by the Purdue Research Foundation. The standard consisted of two parts; the first was a purdue reference model which defined generic requirements common to all CIM implementations. It was used to define the typical information management and automation control tasks related to the functional requirements for the manufacturing plant (Williams T.J., 1991). Part two defined the implementation of the model to drive standardisation (Chen et al, 2008). Figure 2-3 shows the functional relationships between the functional entities defined in the Purdue reference model. The external entities are shown and these interface to the purdue modeled manufacturing system (Williams T.J., 1991).

The Purdue Reference model continued to be developed as a foundation for the standardised functional requirements and data flow models. One of the key results is the ISA S95 Enterprise-Control System Integration model which was initially elaborated by the ISA. Currently, this is jointly reworked by ISO TC184 SC5/WG1 and IEC to become an international standard (Chen et al, 2008). The resulting standard IEC/ISO 62264 Enterprise Control Systems Integration is a multi-part set of standards that defines models and establishes terminology for interfaces between plant and business systems (Meyer et al, 2009).

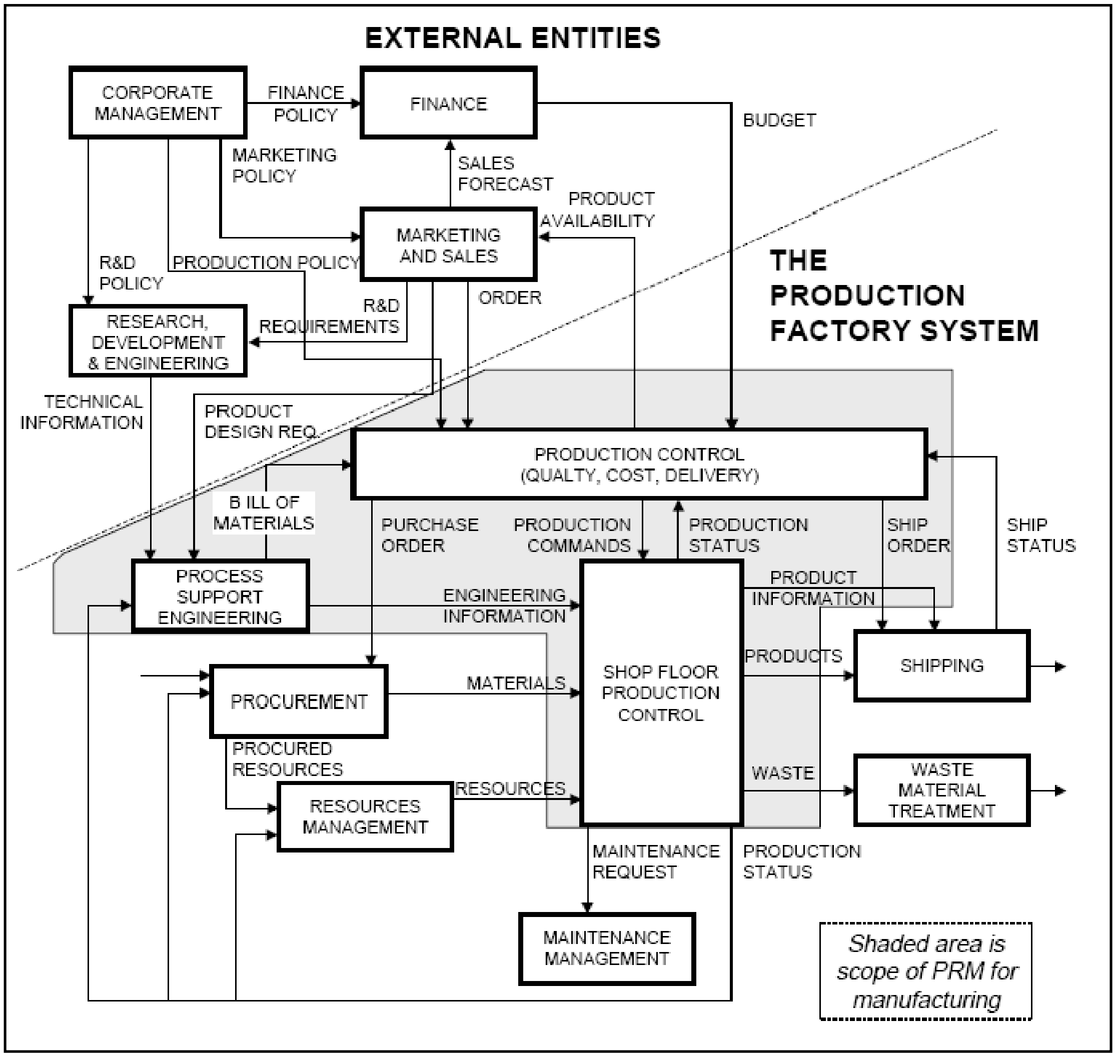

Figure 2-3: CIM Reference Model for Manufacturing (ISA S95.00.01, 2000, p.94)

The Open Applications Group Integration Specification: The Open Applications Group (OAG) is a non profit organisation focused on developing guidelines for integration of enterprise functions. The OAGIS standard has been in development since 1994 and has been founded by ERP vendors. The scope of OAGIS extends the enterprise's reach across the organization and integrates Supply Chain, Financial, MES and Plant Floor systems. OAGIS has approached the integration problem by establishing integration scenarios for a set of applications. Figure 2-4 shows a scenario for capacity analysis and showing integration between ERP, production planning, MES and capacity analysis (MESA 25, 2007).

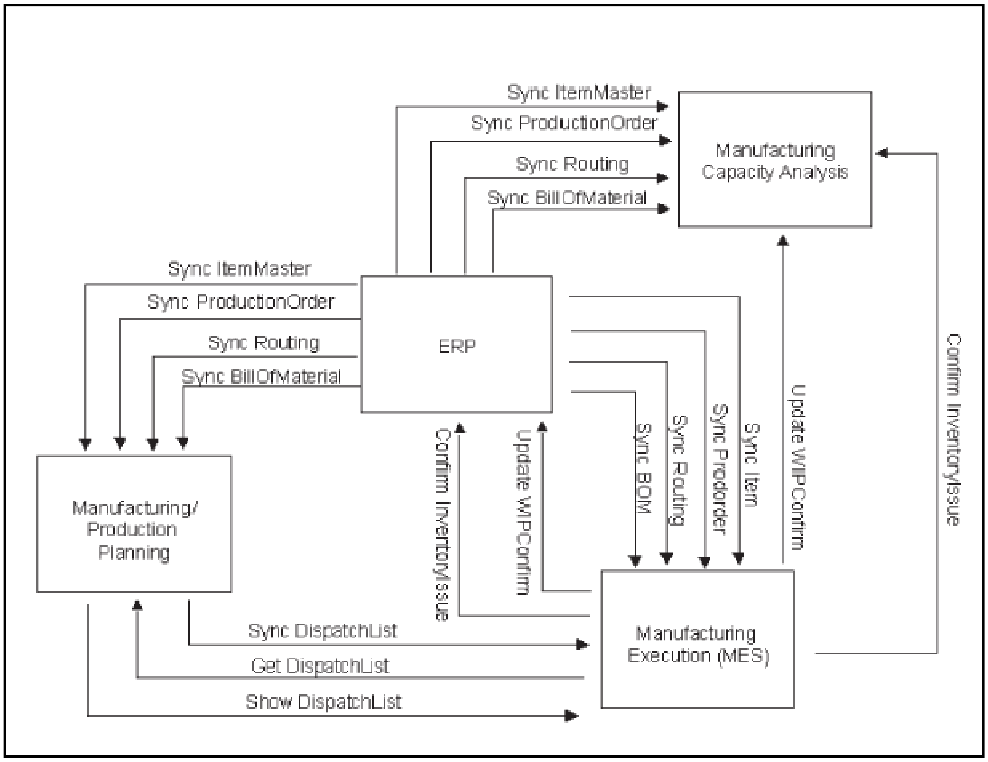

Figure 2-4: Scenario captured from OAGI (MESA 25, 2007)

IT Architecture Considerations: Manufacturing systems are built on IT architecture which is the technological foundation of computers, communications, data and basic systems (Liu, 2002), see Figure 2-5. This IT architecture must enable interface connections between company's MES, the process control and Enterprise Resource Planning Systems (ERP) systems (Meyer et al 2009). Also, authoritative design considerations for each key component of the framework shown in Figure 2.5 are required to direct successful MES system implementation and operation.

This section has therefore shown that the ISA S95 and OAGIS can be used as a good starting point for conducting the necessary baseline analysis of a company's business processes. Also, MES require IT architecture design considerations to ensure the efficient design and operation. Section 2.4 leads to the 2nd hypothesis**: "Functional and IT reference architectures derived from standards and authoritative guidelines is required to ensure that MES optimisation progresses from a well defined, reference architecture.".**

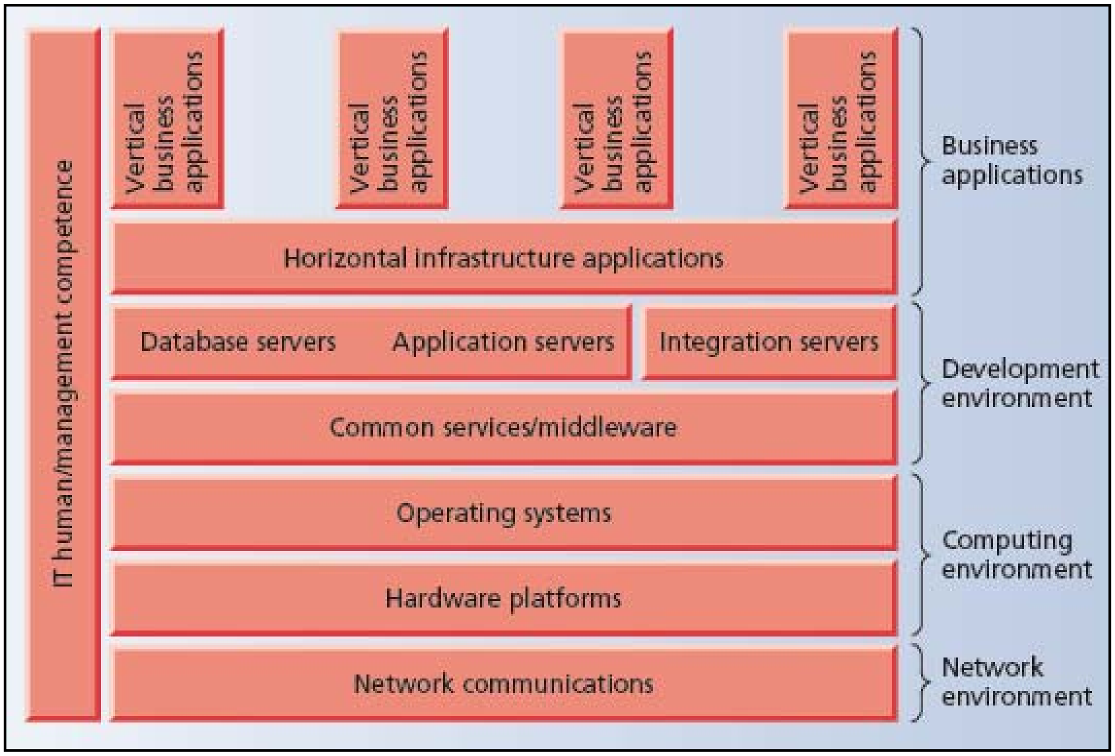

Figure 2-5: IT Architecture Framework (Liu, 2002)

2.5. Human and Organisation Factors

Although heuristics are used to facilitate system design, the execution of an MES integration project is complex and often extended due to organisational and human considerations (Chalmeta, 2001). Therefore, a systematic approach and a formal methodology equipped with reference architectures is required to facilitate a common understanding and also reduce the analysis and design phases of a project (Chalmeta, 2001 and Cheng et al, 2001). Therefore, in order to assist this process, Daclin et al (2006) proposed a methodology consisting of five main phases:

1. As-Is analysis
2. To-Be analysis
3. Gap analysis and solution design
4. Establishment and test of solutions
5. Validation and functioning of deployed solutions

Considering this approach, business process models have been used in the initial analysis phase to describe the functions and data requirements of a business. In this respect, Business Process Re-engineering (BPR) was used to define the study of the company's existing functionality and information systems and their redesign in order to meet the same business objectives at higher performance or lower costs. Also, integrated computer-aided manufacturing definition 0 (IDEF0) was considered to be primarily relevant for designing and documenting hierarchic, layered and modular manufacturing systems (Boucher and Yalcin, 2006).

Section 2.6 leads to the 3rd hypothesis**: "Considering human and organisational factors, MES optimisation requires a formal methodology and systematic approach to ensure a common understanding and integrated approach."**

2.6. Conclusions

This chapter has identified key research hypothesis and issues regarding the problem being investigated. Key challenges for designing, developing and operating MES have been described and discussed considering the experience and research efforts of key contributors to this body of knowledge. The following section will describe the investigative methods used to answer the hypotheses and research questions.

3. METHODOLOGY

3.1. Introduction

The investigative methods chosen will need to answer the hypotheses and questions described in Chapter 2. This chapter describe these procedures used and provides validation from authoritative literature. Table 3-1 shows where the research question and hypothesis from Chapter 2 are considered in this chapter.

Table 3-1: Chapter 3 Reference to Research Question and Hypothesis

#	Research question and hypothesis	Chapter
Research Question	How can MES be optimised using a reference architecture developed from standards?”	
1st Hypothesis	MES enable integration and interoperability between plant and business systems however, functional reference architecture is required to guide MES optimisation. .	3.3, 3.4.
2nd Hypothesis	Functional and IT reference architectures derived from standards and authoritative guidelines is required to ensure that MES optimisation progresses from a well defined, reference architecture.	3.4, 3.5
3rd Hypothesis	Considering human and organisational factors, MES optimisation requires a formal methodology and systematic approach to ensure a common understanding and an integrated approach.	3.3

3.2. Definitions Considered in this Research Report

In the 1990’s MESA described MES as “systems that deliver information that enables the optimization of production activities from order launch to finished goods. Using current and accurate data, MES guides, initiates, responds to and reports on plant activities as they occur. The resulting rapid response to changing conditions, coupled with a focus on reducing non value-added activities, drives effective plant operations and processes. MES improves the return on operational assets as well as on-time delivery, inventory turns, gross margin and cash flow performance. MES provides mission-critical information about production activities across the enterprise and supply chain via bi-directional communications." (MESA 6, 1997). Considering this definition, the term Manufacturing Execution systems refers to the 11 functions for a production system defined by Manufacturing Enterprise Solutions Association (MESA) (Meyer et al, 2009). ISA S95 used these guidelines and extended them into guidelines and standards or batch processes S88 and general processes SP95 (Meyer et al, 2009). Considering these sources and descriptions of MES, Boucher and Yalcin, 2006 indicated that typical MES functions are as follows:

- Dispatching and monitoring production by releasing work orders to the shop floor and tracking work in process inventory.
- Detailed scheduling associated with specific production units in order to meet specific performance criteria.
- Data collection from the factory floor operation to provide a history of plant events.
- Quality data analysis notifying personnel of out of tolerance data received from the lowest level control systems.
- Product history recording providing an account of product genealogy for regulatory and customer processes ensuring efficient tracking of a specific product manufactured by a specific person or equipment under recorded conditions.

During the 1980s and 1990's the term Manufacturing Execution Systems (MES) described the set of manufacturing applications which enables manufacturing by integrating planning and control functions with execution functions (ARC, 2003) (see Chapter 1). A manufacturing system is defined as "The arrangement and operation of machines, tools, material, people and information to produce a value-added physical, informational, or service product whose success and cost is characterised by measurable parameters.", (Cochran, 2001). Morel et al (2007) and Nagalingam and Lin (2008) indicate that MES represents a new and practical approach to link information with action on the shop floor and so help the managers in improving quality, response and profitability in the operation.

All these considerations support the MESA definition and ISA S95 guidelines. Considering all these definitions, for this research report, MES is defined as follows: “Manufacturing Execution System are manufacturing information and communication system operating across a manufacturing organisation, integrating plant floor and business systems enabling increased operational profitability and regulatory compliance.”

Considering this, a plant floor or manufacturing system is defined as “The arrangement and operation of machines, tools, material, people and information to produce a value-added physical, informational, or service product whose success and cost is characterized by measurable parameters.”, (Cochran, 2001). Business systems or planning systems refer to system responsible for planning plant floor and manufacturing functions and activities; these are usually ERP systems such as financial, legal, sales and distribution, human resource management and project management functions (Boucher and Yalcin, 2006, Meyer et al, 2009).

3.3. MES Optimisation Approach

This section describes the MES optimisation approach adopted in this research. The traditional key phases used in enterprise system design are conceptual, design, implementation, execution, testing and support phases, see Figure 3-1.

The conceptual phase focuses on the logical design of functional and data requirements. The design and implementation phase involves the selection and deployment of the IT Architecture such as database management system, hardware platforms and the communication medium. During the execution phase the concept models are coded in a software language before being testing and placed into operational mode (Boucher and Yalcin, 2006).

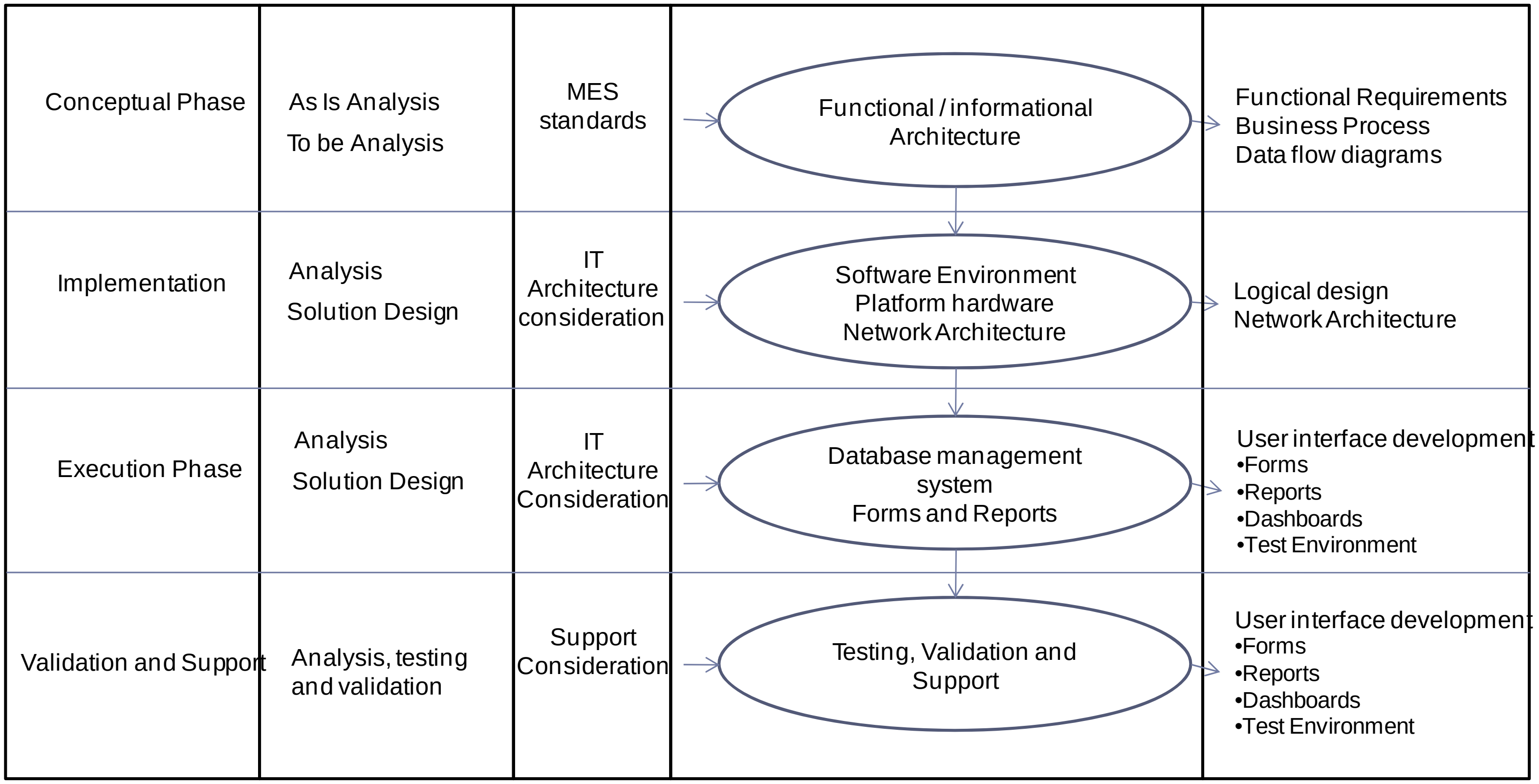

Figure 3-1: System Design Process (Daclin et al, 2006, Boucher and Yalcin, 2006)

Figure 3-1 shows a proposed system design process which allows for system interoperability. The process consists of four phases which aim to include organisational, human and technology elements (adapted from Daclin et al, 2006, Boucher and Yalcin, 2006):

1. Conceptual Phase
2. Implementation phase
3. Execution Phase
4. Validation and support

During the conceptual phase the functional reference architecture is required to describe the functional requirements and system design (Daclin et al, 2006, Meyer et al, 2009). In this research report, the functional reference architecture is used to generate a questionnaire which is applied to analyse the as-is manufacturing systems and also to capture the stakeholders functional requirements. The scope of this analysis is limited to production, inventory, maintenance and quality systems. Information is sourced from training manuals, engineering design documentation, management meetings, operational meetings and also by interviewing stakeholders.

Considering the information captured, the analysis will proceed by identifying gaps between resulting information and generic requirements found in the functional and IT reference architecture. Based on the gaps identified and on opportunity selection criteria the analysis phase should result in a proposed implementation roadmap to improve manufacturing systems and operations.

The MES optimisation approach described in this section seeks to answer the research question. Should the hypothesis developed during the research be accepted, then this will justify the reuse of the reference architecture at similar operations at Sasol. If the hypothesis is rejected, then appropriate reasons should be presented and a future study proposed.

3.4. Functional Reference Architecture Development

Considering the MES optimisation approach described in Figure 3-1, a requirement in the analysis phase is a functional architecture to optimise MES. The functional architecture is derived from relevant standards and therefore the MES standards were assessed based on review of literature and considerations from the Sasol case study.

The functional architecture developed should consist of business process models that adhere primarily to the IDEF 0 modeling methodology. IDEF 0 is a modeling methodology for designing and documenting hierarchic, layered, modular systems. The building blocks of IDEF0 are shown in Figure 3-2.

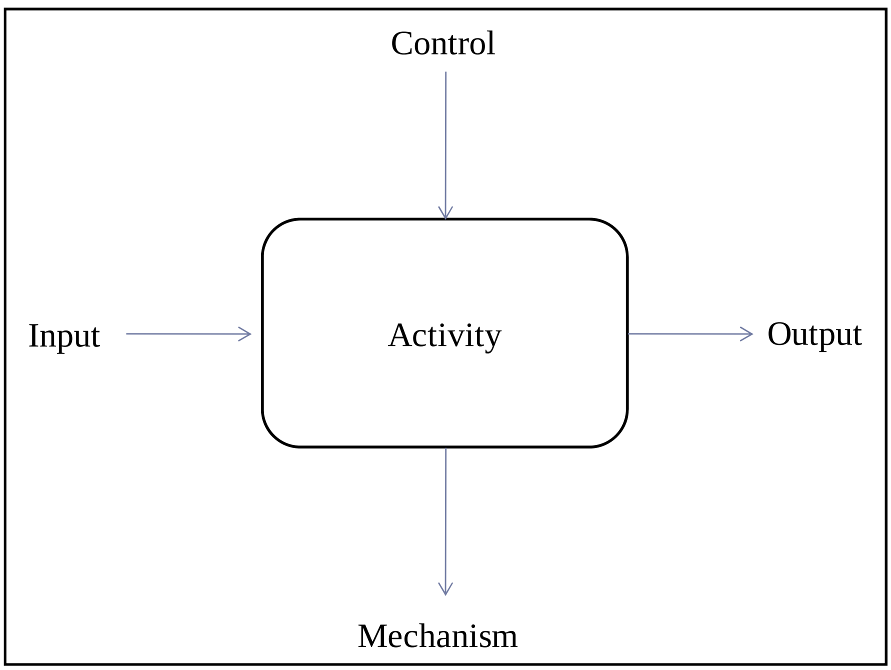

Figure 3-2: IDEF0 activity box and connecting arrows (Boucher and Yalcin, 2006)

The following key information should be shown in the business process models (Daclin et al, 2006, Boucher and Yalcin, 2006):

- The information flows between and within the functions and sub-functions. For example, in the case of the production function, the flow of information between production planning and the production execution sub-function will be described.

- The mechanism or resources used in performing activities specific to that function.
- The governing specifications and policies that provide guidelines for function or activity execution.
- The objective and description of each activity or function.
- The enabling MES application that could be used for that function.

The word architecture is used to indicate that the model has a layered/hierarchal structure. The business process models are used to describe the functions and data requirements of a business and the interfaces between the different functions. In this respect, Business Process Re-engineering (BPR) is used to define the study of the company's existing functionality and information systems and their redesign in order to meet the same business objectives at higher performance or lower costs (Boucher and Yalcin, 2006). This research report uses the Sasol defined business process modeling method based on the IDEF 0 methodology, Appendix B describes this method in more detail. .

3.5. IT Architecture Considerations

Considering the MES optimisation approach described in Figure 3-1, a requirement in the analysis phase is the development of IT architecture considerations to ensure that MES implemented are designed efficiently. Therefore, this section describes considerations from components of the IT architecture used to guide the MES system design. The network architecture is a depiction of how various layers of the functional hierarchy communicate with each other (Boucher and Yalcin, 2006). Figure 3-3 shows a representation of the network architecture aligned to functional hierarchy.

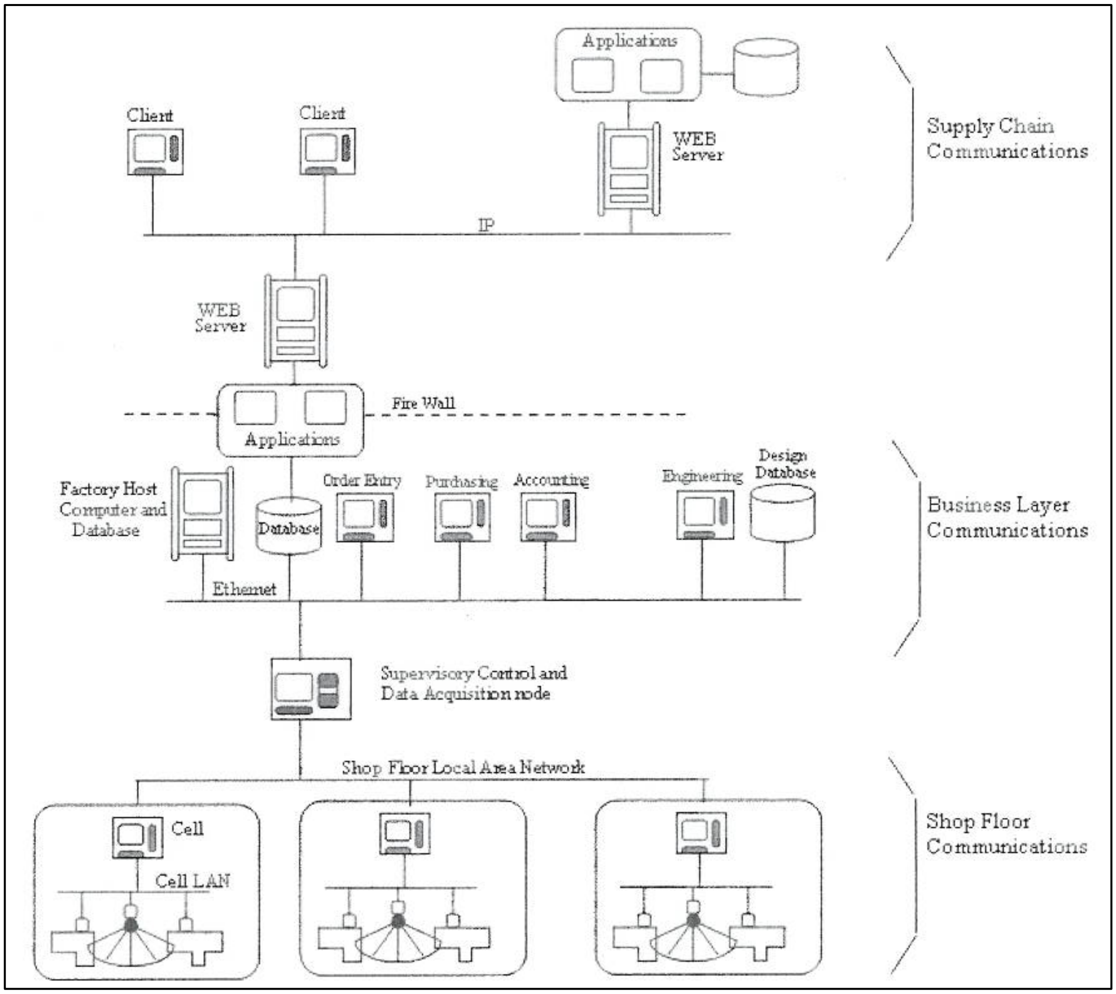

Figure 3-3: Typical Network Architecture (Boucher and Yalcin, 2006)

Manufacturing Applications are usually managed at the business layer and include applications used to enable functions such as production planning and scheduling, maintenance management, logistics and maintenance systems. Considering the CMM model, vertical applications are used to integrate plant and financial and planning functions whereas horizontal applications are used to integrated plant to supply chain functions (Gorbach, 2004).

Also, these manufacturing applications are managed on physical IT hardware such as application servers, databases or plant historians where they are used to handle the data that must be accessed on a near real time basis. The database is the central component of the MES system and therefore has high performance requirements (Meyer et al, 2009). Consequently, key considerations for the network architecture to enable an MES are centralised database, near real time data collection, multiple role based user views, time or batch tagged records, data integrity and security mechanisms. The databases are required to have time tags if storing continuous process data, while batch process data is related to manufacturing batches attributes such as start and end time (Williams T.J., 1991).

Also, many of the data processing tasks can be completed in the database using stored procedures, however an application server or a script engine may be required to optimise user experience due to faster processing speed. Considering the interface between MES and control systems, the use of interface adaptors is required to transfer data between the systems. This may be achieved using standard interfaces such as the object linking and embedding (OLE) for process control (OPC) servers. In layers above the control system, technologies such as web services are used to present data to business applications and this is often achieved using XML type interface objects or java scripts (Boucher and Yalcin, 2006).

Considering the MES application and foundation IT hardware, the computing environment refers to the operating system and base system installation. In this context, the components of the MES architecture are logically grouped ensuring easier management allowing MES to operate with hardware and base system independence. This will allow for MES to be managed easier, reducing IT operational costs and costs associated with maintaining a changing IT landscape (Meyer et al, 2009 and Liu, 2002). Due to this requirement, suppliers are required to deliver systems that are compatible with latest releases of hardware, operating systems and base system installations.

In view of the MES architecture and considerations from literature, a table of criteria was developed as seen in Appendix G, Table G-1. These criteria will support the initial design of the systems to ensure that MES identified are efficiently implemented and operated.

3.6. Conclusions

This chapter has focused on elaborating the approach and methodologies used to answer the research question and hypothesis identified in section 2. The validation of these techniques was achieved using reference to authoritative sources. A key consideration is that MES integration projects are complex due to human and organisation factors. Therefore, system development and optimisation require guidance from functional architecture and IT architecture considerations. Consequently, this research report will focus on developing and applying functional reference architecture consisting of business process models. The MES system implementation will also require guidance of IT reference architecture considerations. The next chapters will focus on showing the resulting functional architecture and it application to optimise MES design aligned to IT architecture considerations.

4. ANALYSIS OF DATA

4.1. Introduction

The previous chapter has developed the methodology to be applied in optimising MES. Considering this methodology, this chapter will show the resulting functional reference architecture developed and subsequent application at Sasol Steam Station Plants 1, 2 and 3 located in Sasolburg, South Africa. IT architecture considerations are used as a guide for efficient MES system design and resulting implementation. Figure 4-1 shows the roadmap and core focus of this chapter.

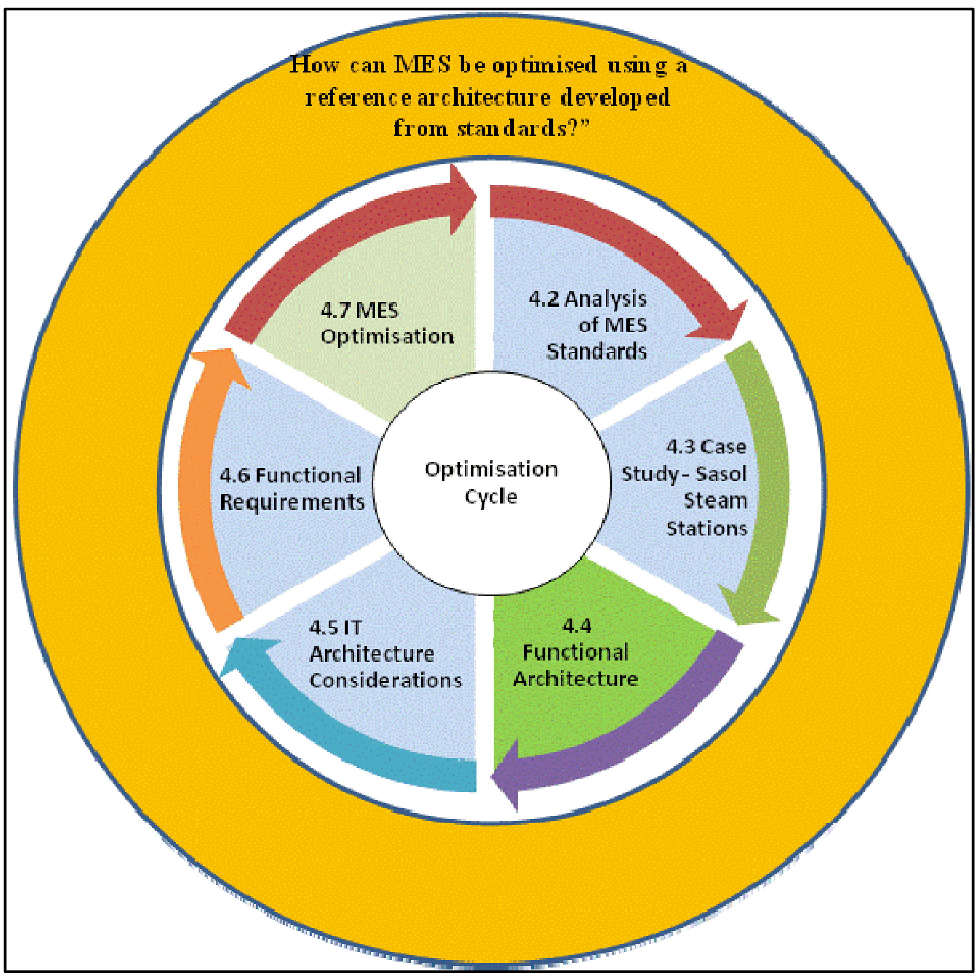

Figure 4-1: Chapter Roadmap

Table 4-1 shows the sections in this chapter where reference and discussion is specific to the hypothesis of chapter 2.

Table 4-1: Chapter 4 Reference to Research Question and Hypothesis

#	Research question and hypothesis	Chapter
Research Question	How can MES be optimised using a reference architecture developed from standards?”	All
1st Hypothesis	MES enable integration and interoperability between plant and business systems however, functional reference architecture is required to guide MES optimisation. .	4.4, 4.6
2nd Hypothesis	Functional and IT reference architectures derived from standards and authoritative guidelines is required to ensure that MES optimisation progresses from a well defined, reference architecture.	4.2, 4.4, 4.5
3rd Hypothesis	Considering human and organisational factors, MES optimisation requires a formal methodology and systematic approach to ensure a common understanding and integrated approach.	4.3, 4.4, 4.6, 4.7

4.2. Analysis of MES standards

A key requirement for functional architecture development is the assessment of the relevant standards; this section describes the ISA S95 and OAGIS standards. Table 4-2 compares these standards as summarised from Appendix C.

Table 4-2: Review of ISA S95 and OAGIS MES Standards

Model	Strengths	Limitations
ISA 95	• Promotes vendor collaboration (Gorbach, 2004). • Includes considerations from the MESA model and the Purdue Reference Model (Meyer et al,	• ISA is driven from an instrumentation perspective focusing on vertical integration. • There are generic functions and activities and the standard functional

Model	Strengths	Limitations
	2009). • Recognised as industry standard since 2003, ISA S95 is referred by International Electro technical Commission (IEC) as IEC 62264 (Meyer et al, 2009). • Used more in the Oil and Gas industry (MESA 25, 2007).	and object model requires modification for different operations. • Focused on integrating plant floor and business systems, there is limited horizontal integration with supply chain applications.
OAGIS	• Promotes vendor collaboration (MESA 25, 2007). • Interfaces to the ERP functions with other enterprise applications. (MESA 25, 2007).	• Driven from ERP perspective focusing on horizontal integration. • There are generic functions and activities and the standard functional and object model requires modification for different operations. • It does not provide holistic view of manufacturing operations but provides scenarios and is focused on data interchange.

In 2006 ISA created a Manufacturing Interoperability Guideline Working Group as a collaborative venture of ISA, MIMOSA, OAGi, OPC and WBF to improve and expand the ISA S95 standard (ISA, 2006). A key consideration is that ISA S95 does not include implementation mapping to XML and this shortcoming is being developed as an extension of the effort of part 5 of the standard (WBF, 2007). One of the key design considerations is to use a standard message interface which will reduce the interface development complexity (MESA 25, 2007). Considering this shortcoming in definition of message interfaces, both standards specify the content of information to be exchanged between functions and not the mechanism. Table 4-3 shows a summary of comparison between standards considering the research issues, this has been summarised from Appendix C, Table C-4.

Table 4-3: Contrast of ISA S95 and OAGIS considering Research Issues (Appendix C)

#	Research Issues	Comment
1	Industry focus	Compared to OAGIS, ISA S95 is focused on the Energy industry and has been successfully applied in reported cases (MESA, 25 2007).
2	Vendor Adoption	The ISA S95 standard is adopted more predominantly by companies and vendors in the Oil and Gas industry.
3	Vertical and horizontal integration problem	The focus of this research is the plant to business vertical integration and ISA S95 describes these interfaces in the activity models more clearly as compared to the BOD found in the OAGIS.
4	Focus	The ISA S95 standard is focused on a functional model and will enable the conceptual design. In contract the OAGIS is largely focused on machine code which is a requirement of detailed solution design phase.
5	Extensibility	ISA-95 provides a generic activity model for the MES whereas the OAGIS provides models related to specific manufacturing scenarios.

Considering the limitations of the research and the identified research problem, this research report is focused on the conceptual layer of the software development lifecycle. Therefore, the ISA S95 standard has been used to develop the functional reference architecture. The following section will continue to describe the case study where the MES optimisation approach is applied.

4.3. Case Study - Sasol Steam Stations

Sasol is an innovative and competitive global energy company. It has a workforce of 30 000 people worldwide. Figure 4-2 shows Sasol’s 15 business units; this case study is focused on the Sasol Infrachem business unit specifically on the Utility Services Department in Sasolburg.

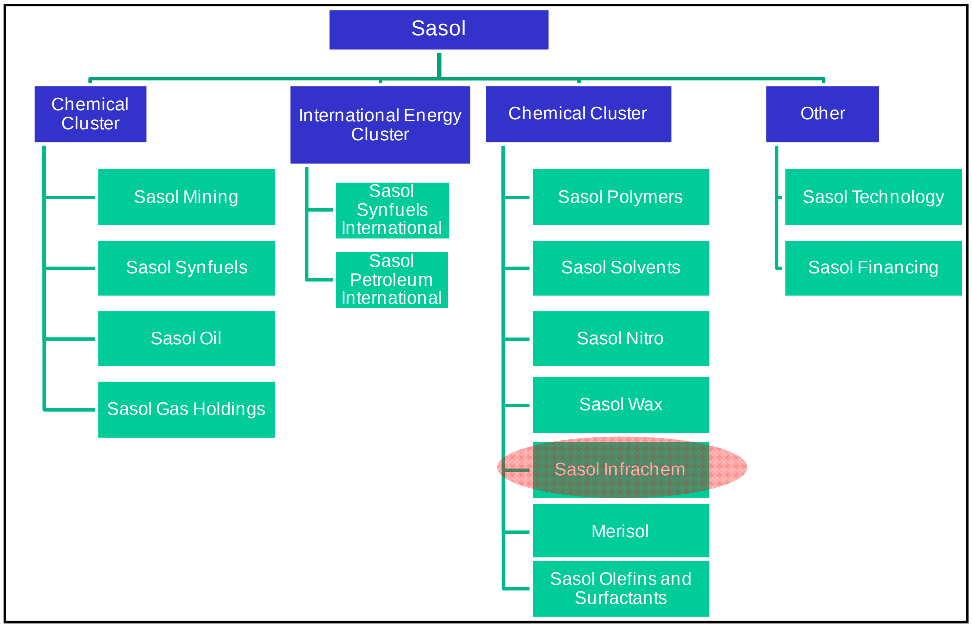

Figure 4-2: Sasol Business Units

Sasol Infrachem converts Natural Gas into synthesis gas for use as petrochemical feedstock. An average total of 39.3 million GJ per annum of natural gas is imported to the Sasolburg using pipeline routed from gas fields in Mozambique. This raw material is beneficiated into Ammonia, Waxes and Alcohols. Operational efficiency is ensured by maintaining stability of the business and optimal functioning of the plant. A central team called process coordination facilitate and conduct optimal distribution of gas and utilities to Sasol plants located in Sasolburg. The Process Coordinators apply their knowledge of the gas loop and utility value chains to optimise proportional distribution according to service agreements and effective production planning based on client requirements (Gabriel, 2010).

The Utilities Service Department is a central function that aims to cost efficiently control and effectively supply services to the rest of the plant. The key services include air, water and steam; centralisation ensures that co-ordination of reliable supply to each plant and also maintenance is enabled cost effectively. Considering this background, this research report aims to optimise the Manufacturing Executions systems which enable the Steam Station plant to remain stable and reliable to customers.

Figure 4-3 shows a high level overview of the Steam Stations supply chain. Coal is fed to Steam Station 1 and Steam Station 2 boilers via conveyor belts. At coal handling the coal is stored in bunkers to have buffer capacity to a maximum of 450 tons. Coal is then fed to the mills where it gets pulverized and thereafter coal silos buffer stock to ensure interrupted supply. An exhauster fan then blows the fuel and air mixture into the combustion chamber of the boiler. Steam Stations 1 and 2 consume an average of 330 tons of coal per hour. The total silo storage capacity is 20 000 tons (Steam Station 1) and 15 000 tons (Steam Station 2). The Steam Stations produce high pressure steam at 38 bar, medium pressure steam at 17 bar and 12 bar and low pressure steam at 2.4 bar. The major portion of the power requirements for Sasolburg site is generated at Power Stations 1 and 2. Electricity is imported from the Eskom grid to make up the short-fall in internal supply. Steam Station 3 provides air, demineralised water and low and medium pressure steam to plants.

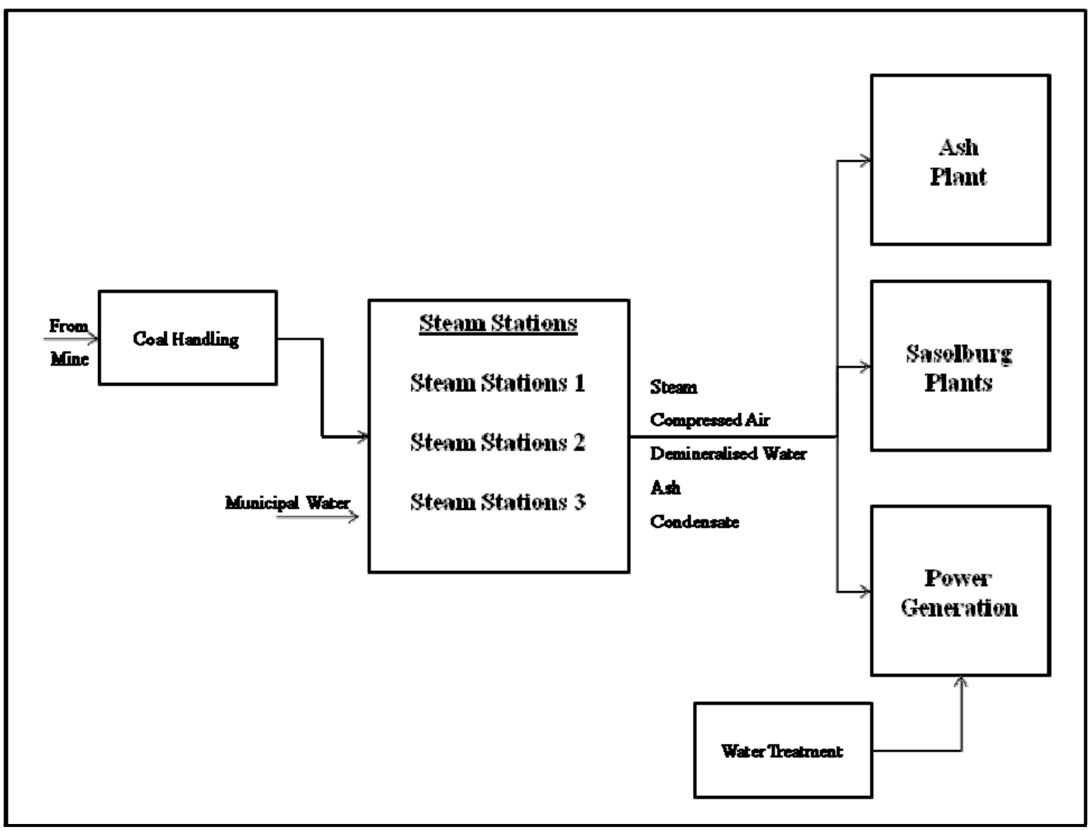

Figure 4-3: Steam Stations Value Chain Overview

Steam Station 1 consists of 8 boilers built between 1954 and 1965. The steam capacity of these boilers is 140 tons per hour. Steam Station 2 consists of boilers 9 – 15 built between 1976 and 1983. Boilers 9 – 12 have a steam capacity of 145 tons per hour. Boilers 14 and 15 have a steam capacity of 155 tons per hour. Almost a third of the 38 bar steam generated from Steam Stations 1 and Steam Stations 2 is used for power generation. The remainder of the steam is then supplied to the other business units and outside consumers. Steam Station 3 provides compressed air, demineralised water and low and medium pressure steam. Equipment managed includes compressors, reverse osmosis plant and demineralisation plant. The steam letdown stations are situated at Steam Station 3. Figure 4-4 shows the Steam Stations management structure.

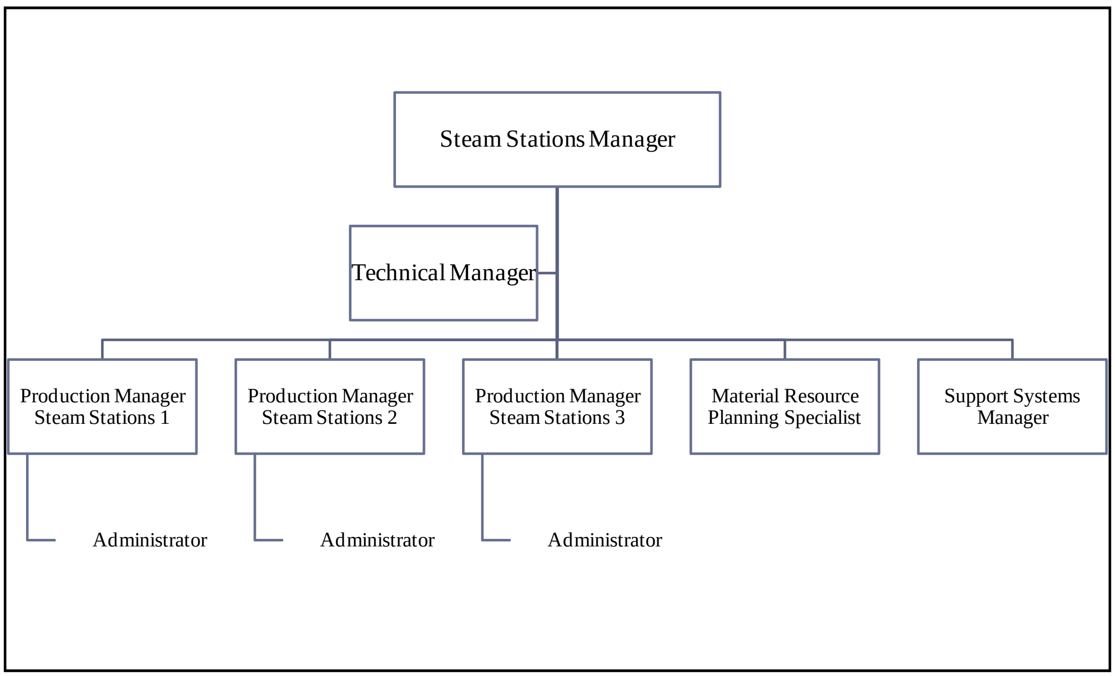

Figure 4-4: Steam Stations Organogram

Considering the Steam Stations mission to provide utilities reliably to plants in Sasolburg, the utility plant is therefore considered a critical part of the manufacturing value chain. The following objective was presented to the Steam Stations Management as a benefit to allowing this research to continue within their operations. “This initiative is focused on improving the Steam Stations operational efficiency by investigating and proposing methods of optimising manufacturing executions systems including production and inventory, maintenance and quality activities." In this context of the Sasolburg utility operations the following section describes the approach and the functional architecture developed to optimise MES at the Steam Stations Plant.

4.4. Functional Architecture

The business process modeling methodology described in Appendix B formed a core component of the reference architecture for capturing functional requirements and identifying interfaces between plant and business systems. This section will describe the results of the functional architecture development and application. The value added chain diagram shown in Figure 4-5, describes the highest level processes in scope for the research. These processes describe the activities that are executed in managing the Steam Stations Operations and include Production and Inventory, Maintenance and Quality Management processes.

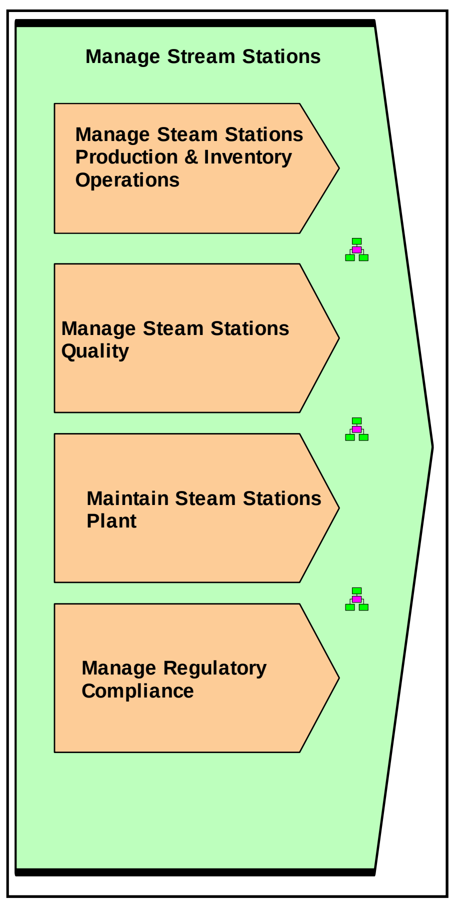

Figure 4-5: Macro Process Manage Steam Stations

Figure 4-6 shows a screenshot of the ARIS modeling toolset used to develop and manage the business processes.

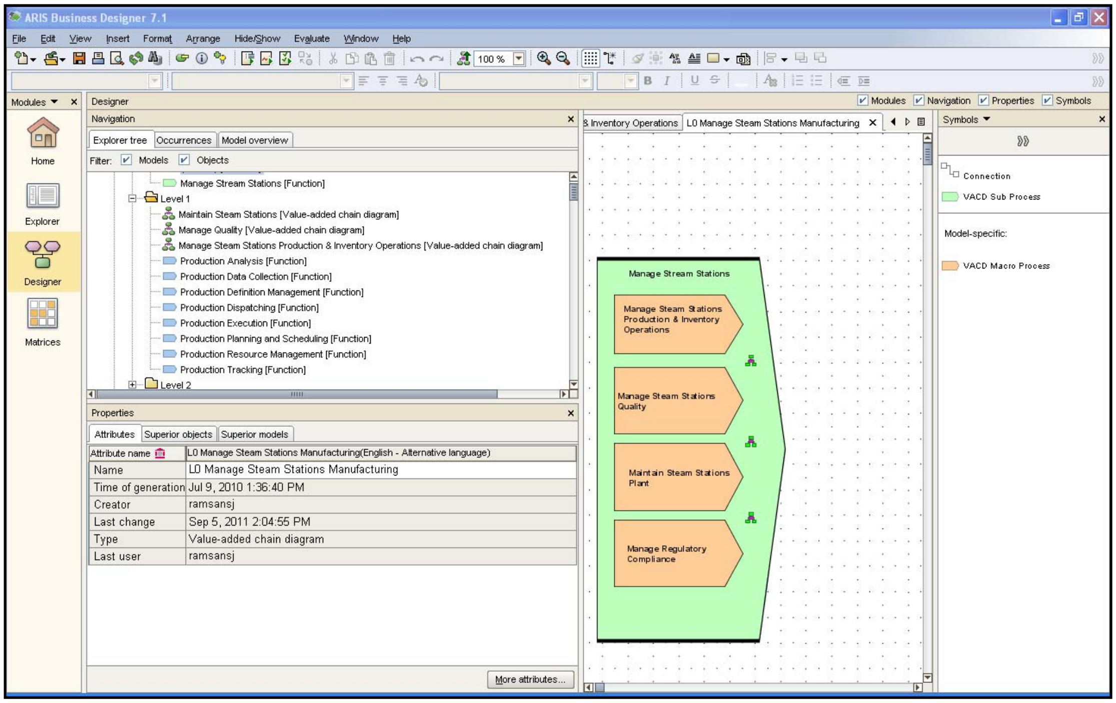

Figure 4-6: ARIS business process modeling tool

Table 4-4, shows the appendices where the Functional Architecture is described. Appendix C, Section 1 describes the ISA S95 functional models and information flows considered when building these business processes.

Table 4-4: Functional Reference Architecture

Appendix	Business Processes
Appendix D	Manage Steam Stations Production and Inventory
Appendix E	Maintain Steam Stations
Appendix F	Manage Steam Stations Quality

Table 4-5 shows the cross reference between the ISA S95 functions as described in part 1, the activity models defined in ISA S95 part 3 and the business process found in the functional reference architecture (ARIS business processes). Table 4-5 also shows processes not modeled however, in these cases the interfaces to these processes are considered. A possible scenario is where the material and energy control function, based on a monthly material reconciliation and material requirements planning provide input information to the procurement function to order stock. Once the procurement function has received this information, further financial transactions will determine the confirmed amount captured in orders and also the confirmed date of delivery.

Table 4-5: Cross Reference Matrix: ISA S95 and Functional Architecture

#	ISA S95 Functional Models (part 1)	ISA S95 Activity Models (part 3)	Functional Architecture (ARIS Business Process L0)
1	Order processing	• Production Operations Management • Inventory Operations Management	Manage Steam Stations Production and Inventory Operations
2	Production scheduling	• Production Operations Management • Inventory Operations Management	Manage Steam Stations Production and Inventory Operations
3	Production control	• Production Operations Management	Manage Steam Stations Production and Inventory Operations
4	Process support engineering	• Production Operations Management • Maintenance Operations Management	Manage Steam Stations Production and Inventory Operations Maintain Steam Stations Plant
5	Operations control	• Production Operations Management	Manage Steam Stations Production and Inventory Operations

#	ISA S95 Functional Models (part 1)	ISA S95 Activity Models (part 3)	Functional Architecture (ARIS Business Process L0)
6	Operations planning	• Production Operations Management • Inventory Operations Management	Manage Steam Stations Production and Inventory Operations
7	Material and energy control	• Production Operations Management	Manage Steam Stations Production and Inventory Operations
8	Procurement	• Not modeled	Not modeled
9	Quality assurance	• Quality Operations Management	Manage Steam Stations Quality
10	Product inventory control	• Inventory Operations Management	Manage Steam Stations Production and Inventory Operations
11	Product cost accounting	• Not Modeled	Not Modeled
12	Product shipping administration	• Not modeled	Not modeled
13	Maintenance management	• Maintenance Operations Management	Maintain Steam Stations Plant
14	Research, development and engineering	• Not modeled	Not modeled
15	Marketing and sales	• Not modeled	Not modeled

The following sub-section describes the business processes Manage Steam Stations Production and Inventory Operations. This process is chosen to demonstrate how the functional architecture was developed using guidance from ISA S95.

4.4.1. Manage Steam Stations Production and Inventory Operations

Appendix D, Figure D-1, shows the level 1 Manage Steam Stations Production and Inventory Operations business process models developed in ARIS and Appendix D, Table D-1, describes the business process models captured including the type of process model and group within the functional architecture. As described in Appendix B, each of the business process models at level 1 are composed of level 2 sub processes referred to as lean Event-Driven Process chain (EPC) models. Considering this methodology, Figure 4-7 (Appendix D, Figure D-6) shows a snapshot of the level 2 sub process, Production Execution Management.

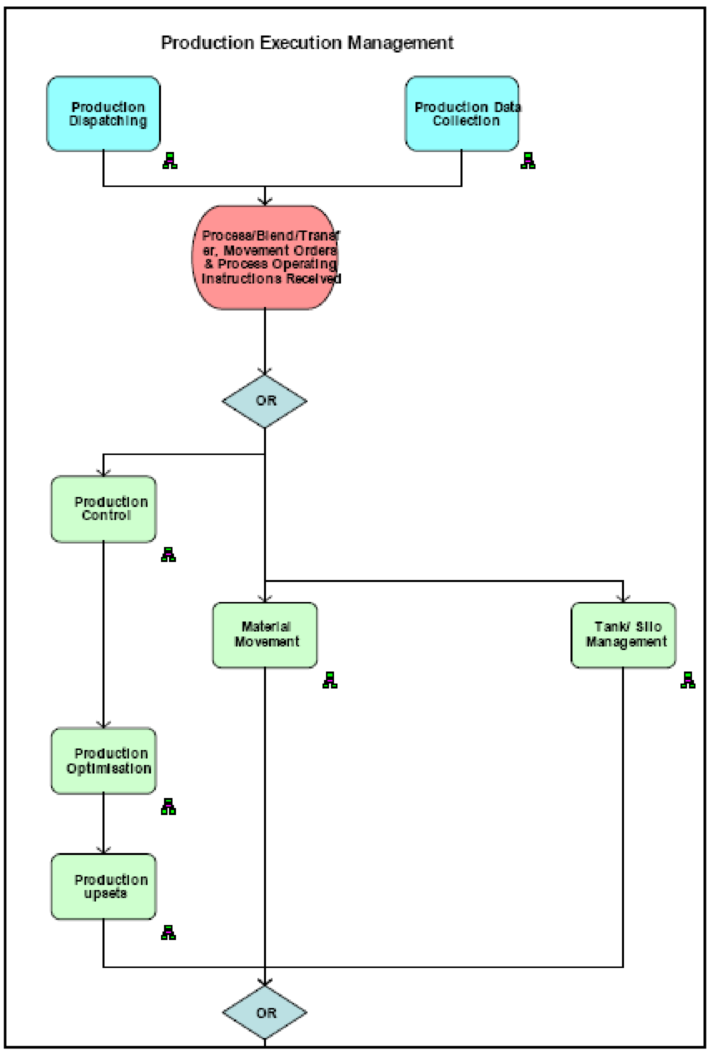

Figure 4-7: Snapshot of Production Execution Management (Appendix D, Figure D-6)

The Production Execution Management process is modelled as a lean EPC as the information flows are hidden in an object called the Functional Allocation Diagram (FAD); this decision can be taken to ensure that process is easier to display and manage. The Production Execution Management process describes the following functionality; production optimisation and control, tank and silo management as well as material movement. This functionality was developed considering the ISA S95 activity model for production execution management, Appendix C, Figure C-5.

The Steam Stations plant is continuous process with a key goal to minimise and manage process upsets rather than manage a varied product range. Considering this characteristic only practical functionality was included in the business models from the ISA S95 activity models. Also, ISA S95 Part 3 describes production execution management as the collection of activities that direct the performance of work, using input from the production dispatch list elements therefore ensuring operations are coordinate to efficiently manufacture product (ISA S95.00.03, 2000).

Considering the production execution level 2 process in Figure 4-7, Appendix D, Figure D-10 shows the activity level (level 3), FAD for production optimisation. This FAD specifies input information, output information, governance considerations, supporting resources and enabling systems for each activity model. Key outputs from this specific activity are upset process messages and the production logs which can be used for shift handover. The production optimisation model is generally enabled by an expert advisory system and this generic enablement is used as discussion points during workshops with Steam Stations personnel.

This section has described the Manage Steam Stations Production and Inventory Operations processes which have been developed using key guidance from the Production and Inventory Operations Management models found in ISA S95. The functional architecture has been decomposed at each layer drilling down from the L0 Steam Stations macro process, to level 1 business process, to level 2 sub-business processes, to lean EPC business process and finally to the functional allocation diagrams. This layered architecture is shown in Appendix B, Figure B-1.

Appendix C, Figure C-4 show the ISA S95 generic activity models that assisted in defining the sub processes at level 1 and 2. In addition, the activity models found in ISA S95 part 3 have been used to guide the development of the level 3 processes composed of lean EPC business processes and functional allocation diagrams. Applying this approach Appendix H, Table H-2 shows the list of processes that form the functional architecture developed; there are 3 level 1 processes, 24 level 2 processes and 94 level 3 processes. Information included in these models and activities will be discussed with Steam Stations personnel to determine the as-is process and functional requirements which will assist in specifying the to-be state. The following section will describe the toolsets to identify where the current MES system can be improved.

4.4.2. Questionnaire Toolset Development and Application

Figure 4-8 shows the agenda used to provide background and justification for Steam Stations personnel to accept the case study. Key highlights were benefits of participating in the case study and the request for involvement of key stakeholders to participate in workshops and one on one interview.

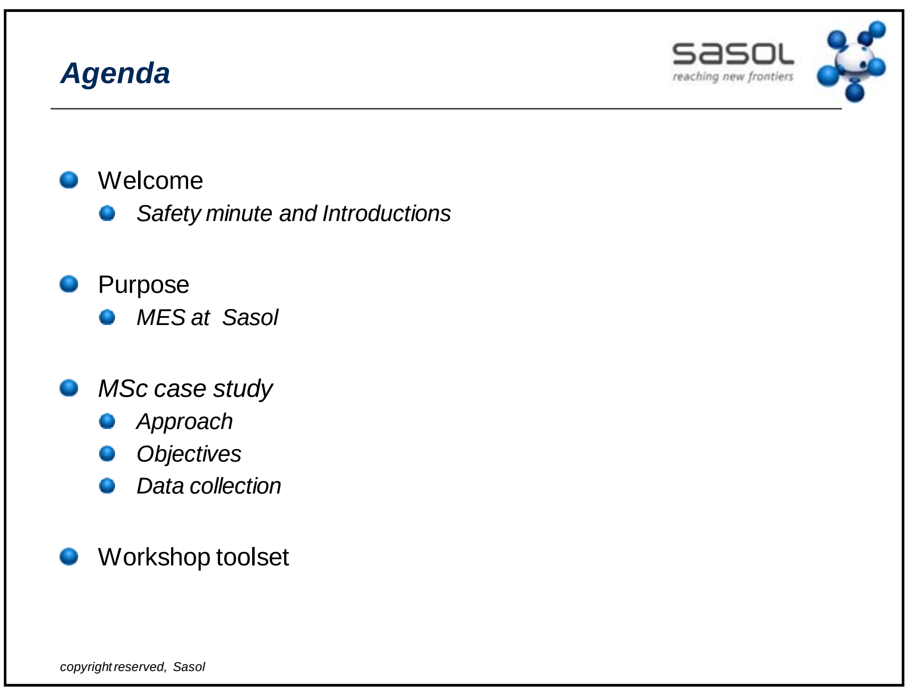

Figure 4-8: Agenda for Steam Stations Case Study (Appendix H, Section 1)

Appendix H, Table H-3 shows the tentative workshop schedule proposed to capture functional requirements from business. The use of a formal methodology, and the request for preparation prior to workshops, ensured that time allocated was beneficial. Appendix H, section 4 and section 5 shows the toolsets to capture requirements, these were essentially a snapshot of the ARIS business process with an adjacent table to capture process information. The adjacent tables have information from business process and functional allocation diagram attributes. This included attributes such as description, input information, output information, stakeholders, enabling system and interfaces.

Considering this Appendix H, section 5 shows the functional requirements questionnaire directed at the stakeholders identified for each workshop; the stakeholder's roles are captured in Appendix H, Table H-8. Using this formal approach and toolsets the requirements capturing process was accelerated and Appendix H, Table H-4 and Table H-5 shows a toolset with information populated. Also Appendix H, Table H-5 shows that questions were added to enrich the workshop or interview process. The criticality of the functional requirements were classified as mandatory, optional or remain the same.

4.5. IT Architecture

IT architecture considerations are required to ensure that the MES system design and operation is aligned to standards and authoritative guidelines. This section will describe the results of the IT architecture consideration development and application.

Appendix G, Table G-1 shows the IT Architecture considerations which will ensure that any new software deployed in the MES landscape is suitably managed. In addition, for brownfield operations where systems are installed these considerations will initiate a change process to ensure the IT assets are suitably managed. Based on these considerations the following section provides some of the key observations found at the Steam Stations.

4.5.1. IT Landscape

At Sasolburg one of the central plant historians is the Aspen Tech Info Plus.21 historians and most plants interface to the site historian to store their data, Appendix G, Figure G-1 shows the Steam Stations IT Architecture. Application stations act as interface between the site historian and the process control system and are able to buffer data should the link to the historian fail. The data is sampled from the control system and stored in the site historian at 30 second intervals. Also, data is available on the site historian in this form for 1 year and this is usually for the functionality required by near real time dashboards and other systems such as expert advisor systems. The process network of Steam Stations 1 and Steam Stations 2 are connected to the Sasol network, therefore they are able to store their data on the plant historian. Appendix G, Figure G-1 also shows that Steam Stations 3 process control system operates as a standalone system and flat files (Microsoft Excel and other) are used to capture data for reporting, feedback and analysis purposes.

4.5.2. Manufacturing Applications

Applications are usually categorised based on the natural functional groupings. Therefore Appendix H, Table H-1 and Table H-2 show the detailed analysis that was carried out to cross reference ISA S95 activities and Steam Station manufacturing processes to generic application functionality. Considering this analysis, Table 4-6 provides a list of the application functionality in scope for analysis at the steam stations. This application functionality is independent of any technology and may be enhanced, aggregated or decomposed based on the technology chosen. This approach ensured that the manufacturing processes presented to the Steam Stations personnel were also described with reference to existing systems therefore, creating an understanding of the possible to-be state.

Table 4-6: MES System Generic Functionality

#	Application	Functionality
1	Document Management System	Used to manage all documents centrally and facilitates workflows.
2	Production Planning and Scheduling System	Manages demand estimation, capacity planning and production simulations to create a production plan.
3	Logistics Information System (LIS)	Enables the operational supply chain. The LIS manages all receipt, transfer and dispatch of material and products. In some cases in process material management is required.
4	Tank and Silo Management System	Provides visual indication of tank levels and provides some predictive scenarios on future scenarios based on current production conditions.
5	Personnel Availability and Shift Management	Personnel Availability Management allows for central management of personnel commitment.
6	Operations Portal	Manages communication to the plant personnel across all functions and can include important safety and operations related messages, the access is role based.
7	Production Log Management	Enables electronic management of logsheets and allows for easier shift handover and production history can be easily referenced.
8	Process Control Systems	These are critical systems which manage the plant and process conditions by controlling the process according to process and safety design configuration. This is a safety critical system and is managed on the process network; usually this system does not allow write access to users from outside of the process network.
9	Production Event Management	May be used to track adverse conditions in the plant and can interface to electronic logsheets for automated event capture.
10	Plant Information Management System	These are central plant historian and plant databases where MES application servers can store and reference

#	Application	Functionality
	(PIMS)	data.
11	Material Reconciliation	Ensures that material consumed is tracked according to plan. Usually this allows for detection of incorrect data which may be due to instrument calibration or adverse operating conditions.
12	Plant Performance Management System	This system is used to provide dashboards and reports to plant for visibility and decision making. Expert advisory systems can be categorised here.
13	Maintenance Strategy System	Facilitates capture of equipment strategies, this system allows for Reliability Centred maintenance and can also be used to troubleshooting using Failure, Modes and Effects Analysis (FMEA) functionality. Task lists are usually developed in this system.
14	Maintenance Execution	Enables the execution and tracking work orders. The system allows tracking of maintenance progress and quality of maintenance activities.
15	Maintenance Inspections	Enables equipment condition to be tracked on a shift or daily basis to check the condition of the equipment; handheld computers equipped with barcode scanners are usually used to capture the data
16	Maintenance Equipment health monitoring online system	This is an online system is used to track the condition of equipment using measuring systems.
17	Work Permit System	This is a safety system which allows for a work order to proceed with correct pre conditions and approvals being met.
18	Maintenance Reporting	Allows for increased visibility to track performance of equipment and of the maintenance teams.
19	Laboratory Information Management System	This is a business-critical system that manages the laboratory processes through site-wide sample workflow management.

#	Application	Functionality
20	Laboratory Inspections	Enables tracking of sample status which maybe the physical location or the status of the sample testing process.

Considering the application functionality in scope, Appendix G, Table G-2 shows some technologies available to Steam Stations. This provides insight into applications that can be leveraged from different sites. The level of MES system maturity at the Steam Stations is assessed using the criteria found in Appendix G, Table G-1 where suitably managed systems are systems which meet more than 80% of criteria. Considering these criteria, Figure 4-9 shows the opportunity for Steam Stations to improve the operations by closing the gap between the current system and fully integrated system. However leveraging this will require review of screening criteria in Appendix H, Table H-7.

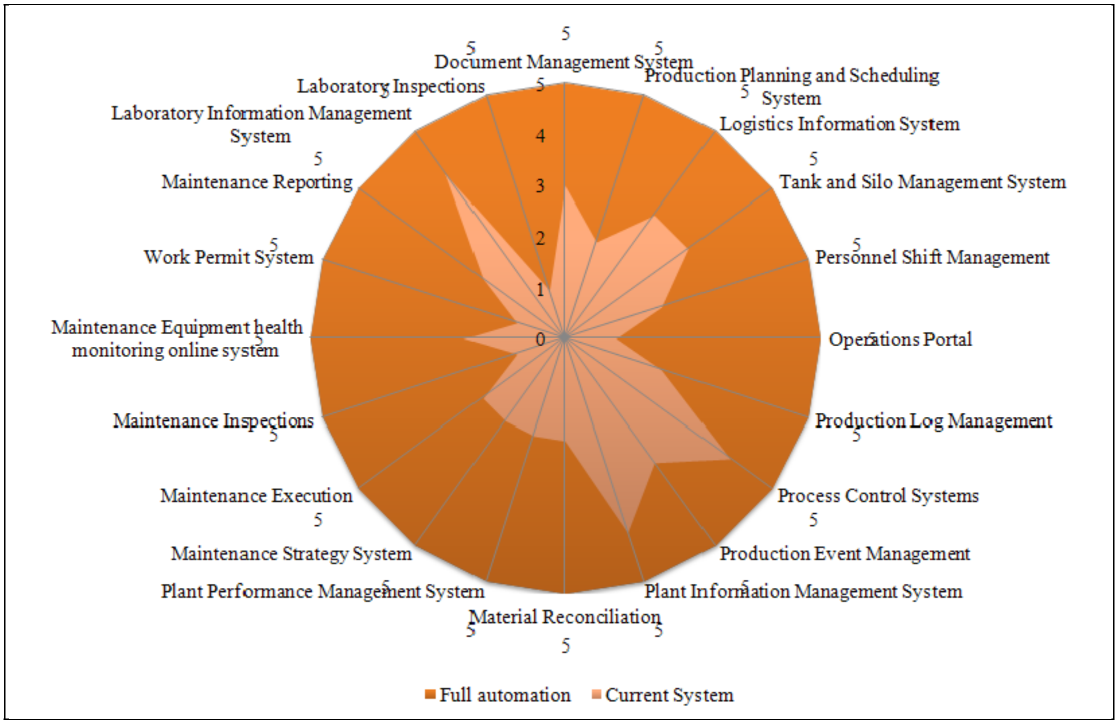

Figure 4-9: Steam Stations MES Optimisation Opportunity (Appendix G, Table G-3)

The analysis in Figure 4-9 is performed per system and a detailed analysis per manufacturing process activity follows in section 4.6. Therefore, considering this initial analysis and opportunities identified, the following section describes the functional requirements identified to improve Steam Stations operations and consequently optimise the current MES system landscape.

4.6. Functional Requirements

Table 4-7 shows appendices where the functional requirements were captured. The questions used in workshops were developed considering the activities from the manufacturing business processes. The questions were used to identify gaps between as-is and to-be system requirements. The requirement criticality and system maturity were used to the implementation roadmap.

Table 4-7: Steam Station Functional Requirements

Business Process	Appendix	Questions used in workshops	Functional Requirements	Requirement Criticality and System Maturity
Manage Steam Stations Production and Inventory Operations	I	Table I-1	Table I-2	Table J-3
Maintain Steam Stations	J	Table J-1	Table J-2	Table J-3
Manage Steam Stations Quality	K	Table K-1	Table K-2	Table K-3

Figure 4-10, Figure 4-11 and Figure 4-12 show the current MES maturity and opportunity to optimise the manufacturing process by improving the system maturity to the required to-be state. Figure 4-10 shows that a key requirement was for Steam Stations 3 to interface to the plant historian, as this is a base system for other applications; section 4.7.1 describes the optimisation opportunities.

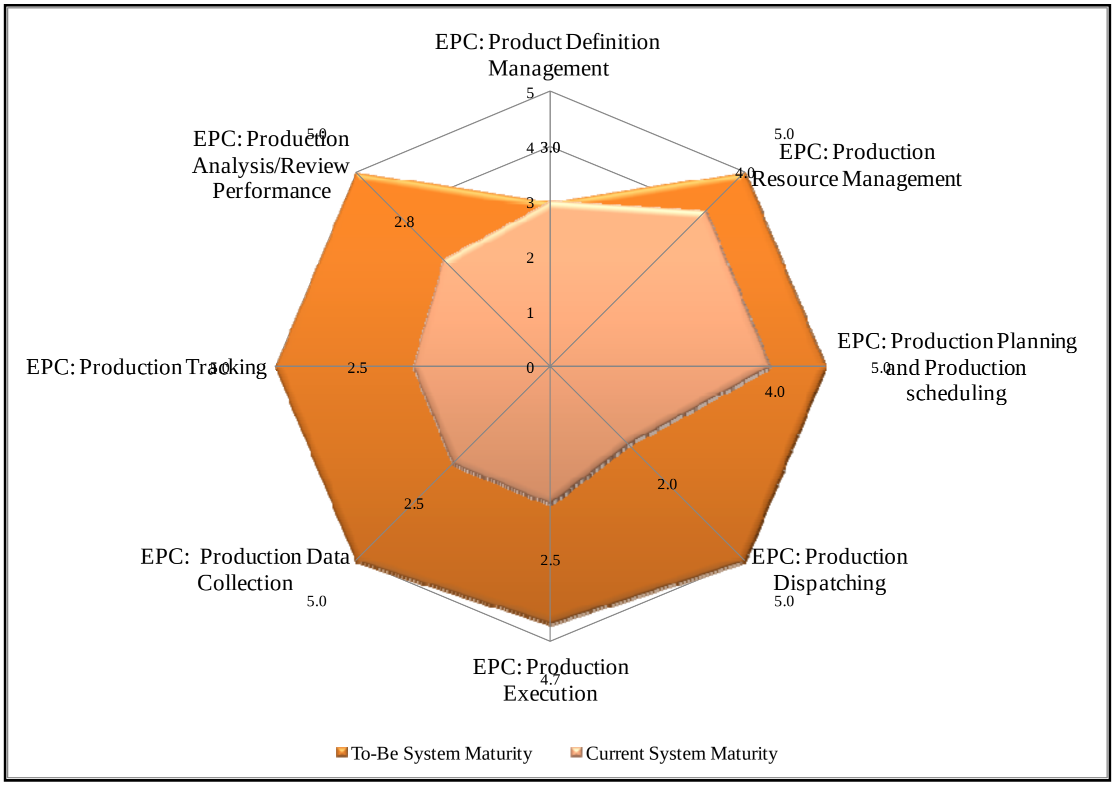

Figure 4-10: Manage Steam Stations Production and Inventory Optimisation Opportunity

Figure 4-11 shows that the maintenance management systems are performing closer to the to-be requirements of Steam Stations maintenance team. However, Maintenance Strategy and Maintenance Inspection Systems are required and enhancements are also required to the maintenance reports, section 4.7.2 describes these improvements.

The process of Managing Steam Stations quality is owned by the Sasolburg Infrachem laboratory, as they provide a service to plants on the site. Figure 4-12 shows that Steam Stations require a sample tracking system to allow visibility of samples being tested, section 4.7.3 describes the requirements.

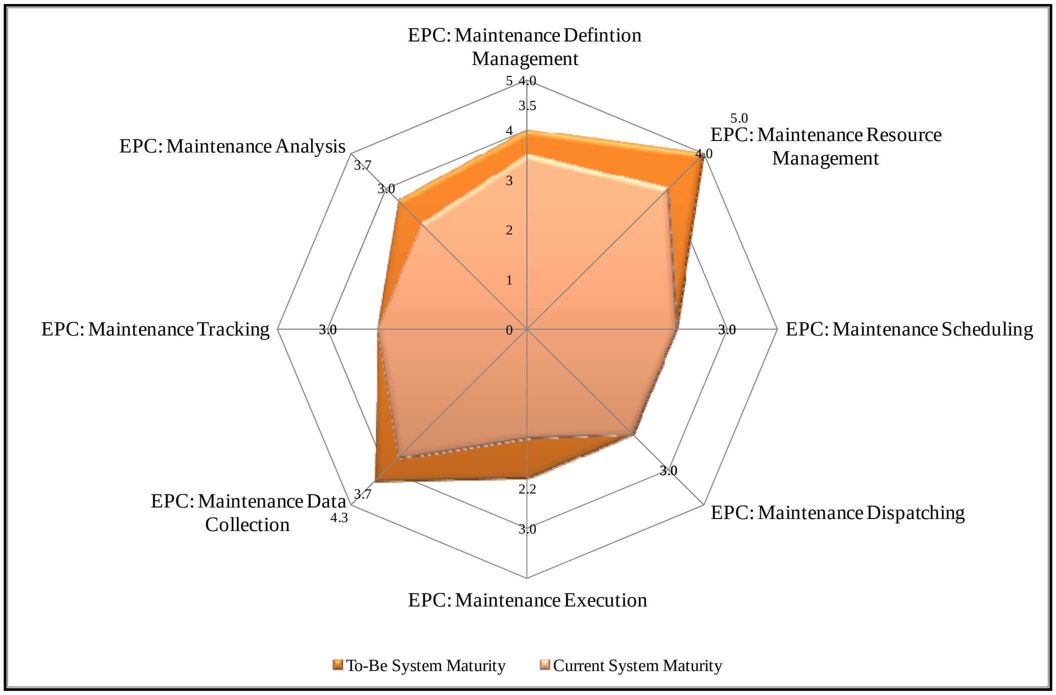

Figure 4-11: Manage Steam Station Maintenance Optimisation Opportunity

Figure 4-12 shows the opportunity to improve Steam Stations Quality Management process.

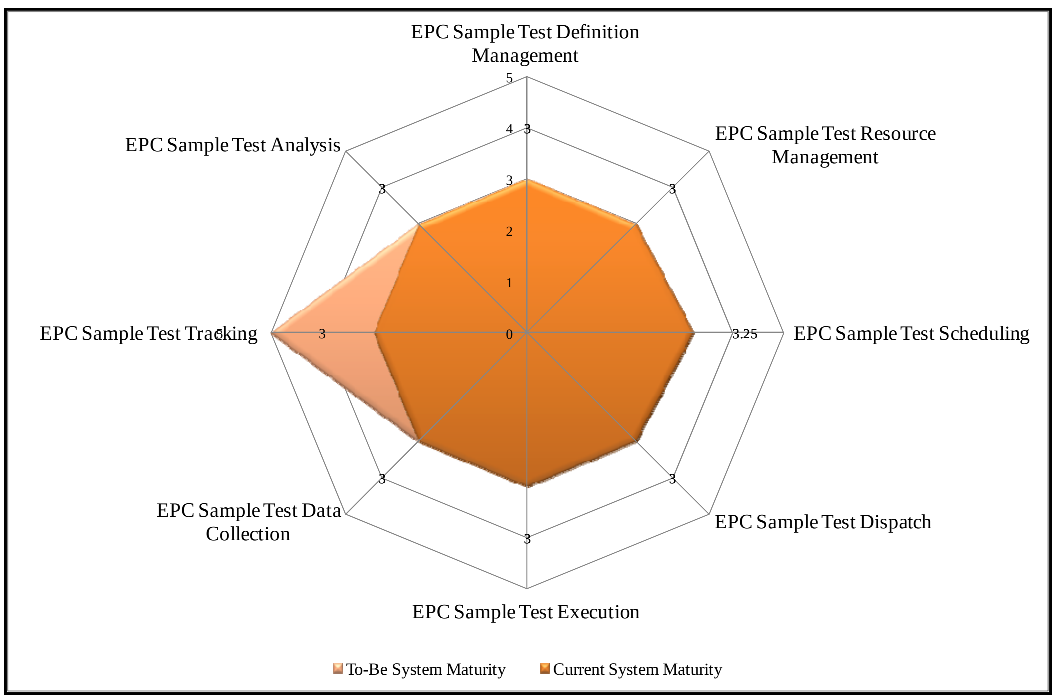

Figure 4-12: Manage Steam Stations Quality Optimisation Opportunity

4.7. MES System Optimisation

During the functional workshops, each requirement and therefore system was rated according to criticality, where:

- Mandatory: System is required to change urgently and project must start in 6-12 months.
- Optional: System change can be delayed and project can start after 12 months.
- Remain the same: System functionality is not required to change.

This section considers the mandatory requirements documented for each process and therefore the following section provides the MES enablement proposed. At this stage of the Software Development Life Cycle (SDLC) the system design is conceptual and therefore these requirements will be discussed with reference to the business process being supported.

4.7.1. Manage Steam Stations Production and Inventory Operations

a) Production Planning and Scheduling System

An integrated production planning and scheduling system is required to define production goals and objectives and align customer requirements with these goals thereby determining resource and capital requirements and monitoring overall manufacturing performance. Improvements are required to the production planning and scheduling system as a large subset is enabled in Microsoft Excel spreadsheets. The processes in scope are Production Resource Management as well as Production Planning and Scheduling and these are described below.

Current Process and technology enablement

Long Term Planning: As part of the annual budgeting cycle and the annual production planning process the Steam Stations confirm the 5 year production demand forecast. The demand for the new financial year is established in a process driven by the Material

Requirements specialist whereby Sasol Mining, Sasolburg Water and Effluent Department, Customer Plants, Power Generation Plant, Process Engineers, Environmental Engineers and Projects Department as well as other stakeholders agree on the future year's utility demand, see Appendix L, Table L-2. The yearly plan is a part of the five and ten year Site Strategic Plan and a prerequisite for each plant is a sales plan to ensure that there is a valid commitment to the forecast utility usage. The ability to meet the forecast demand is dependant on factors such as plant shutdown schedules, plant efficiencies, material availability and personnel availability. This utility demand confirmation process is facilitated using meetings and electronic communications; the outcomes are minuted and the resulting information is captured in spreadsheets which are managed on a shared drive.

Once the expected plant shutdown schedules and production volumes for steam, demineralised water and compressed air are confirmed, the resource commitment process involves taking the committed forecast product demand and calculating requirements for raw material such as water, electricity and coal, see Appendix L, Table L-7. The SAP Production Planning (PP) Module enables the material requirements calculation, however the production demand pushed into SAP is uploaded from Microsoft Excel using flat files. Thereafter, the yearly demand and material requirement plan are decomposed into 12 month buckets enabling the Financial Department to budgeting accordingly.

Medium and Short Term Planning: The medium and short term planning process occurs on a monthly and weekly time period, respectively (see Appendix L, Figure L-1 and Figure L-2. The process is facilitated by the Material Requirements specialist and Administrators who support the three Steam Stations. A Microsoft Excel spreadsheet is use to track and report production, material consumed and plant shutdown schedules in comparison to those forecast (Appendix L, Table L-3). The spreadsheet is updated with data from the plant historian and other manual data sources; data in this spreadsheet is reconciled manually. Also, the medium and short term plans are updated and distributed to the various stakeholders for confirmation prior to being finalised and communicated to Steam Stations production personnel. There is a daily process coordination meeting used to coordinate the plants on the Sasolburg site. This meeting occurs daily and the short and medium term production plans are updated with short term events such as emergency shutdowns, see Appendix L, Table L-1.

To-be process and technology requirement

The Steam Stations personnel would like to remove the functionality from Microsoft Excel spreadsheets and move these to the production planning and scheduling system. The current process of confirming customer demand and shutdown schedule is time consuming and is often iterative due to availability of key stakeholders. Therefore, it is required that the attributes in the yearly, medium and short term production planning Microsoft Excel spreadsheets be captured in a system which facilitates capture of agreed forecast and therefore interfaces with SAP PP automatically to generate a material requirement plan, Appendix L, Table L-2. Also a workflow process is required where customer demand is captured and this will eliminate meetings minutes and shorten the approval process for long term and medium term planning (Appendix L, Figure L-1 and Figure L-2).

The current spreadsheet is used to input the reconciled production figures into SAP via flat file. This flat file sources data from various sources including the plant historian and other spreadsheets, also a manually update is required. Therefore, a data collection and reconciliation system is required to collect data efficiently and enable material balance reconciliation before the data is pushed to SAP. Appendix L, Table L-4, Table L-5 and Table L-6 show typical information are required to determine application configuration requirements.

Key benefits include: reduced effort and increased accuracy in maintaining production planning and scheduling information ensuring better customer relations. Also the system will be more agile allow the ability to adjust and communicate the medium and short term production plans more efficiently even during unexpected production events.

b) Personnel Shift Management

Currently the personnel shift and standby roster are managed in Microsoft Excel by the respective Steam Stations Administrators. The timesheets from production personnel are captured on a weekly basis and compared against the shift roster. The times are then pushed using flat files into the SAP Human Resources (HR) module. A system is required to capture the personnel clocking times and then compare these with shift roster before automatically uploading to SAP HR. This system should also show alerts and reasons for personnel being absent enabling a call out of the standby person. There is an Access Control System on site and therefore another possibility is pulling the employee clock in times and clock out times into SAP HR.

Key benefits include: reduced effort and increased accuracy in maintaining shift and standby rosters ensuring personnel availability status is tracked easily.

c) Logistics Information Systems

The stores coordinators perform monthly audits at the Steam Station satellite stores to keep an inventory list in Microsoft Excel up to date, this data is then uploaded to SAP MM via flat file. Currently the Infrachem warehouse manages inventory on behalf of plants on site. The warehouse has handheld scanners and IT infrastructure that allows for stock level management using handheld devices where a barcode scanner allows tracking of stock entering and leaving the store.

The Material Requirements specialist requires increased visibility at the satellite stores to ensure that critical spares are managed appropriately. The option to move the satellite stores inventory to the central store is being investigated. The other option is to use the handheld computers from the central store to manage the satellite stock levels. Inventory information captured in the handheld scanners can be downloaded at docking workstations at the central store thereafter pushing the information to SAP MM. Also further reports are required from SAP MM on critical spares inventory levels.

Key benefits include: increased visibility to the materials in the stores enabling resource commitment and a higher availability operation.

d) Operations portal

Currently the Steam Stations use Sharepoint as the collaboration technology for the plant; and a Steam Stations web page exists. However, the web page requires update; also this site must have the ability to interface to other MES and document management systems to ensure easier navigation from a central portal. The administrators would like to manage the site content.

Key benefits include: document control, centralised system access and management of MES and other systems.

e) Plant Information Management System

Appendix G, Figure G-1 shows that Steam Station 1 and 2 are connected to the business network; however Steam Station 3 has a standalone process control system. Steam Stations requires the plant systems to connect and store data on the plant historian. This will enable Steam Station 3 to use the site historian and MES applications used by Steam Stations 1 and 2. A preliminary assessment indicates that Steam Stations 3 require hardware which includes network infrastructure and store and forward application server to buffer and transform data being pushed to the Aspen Tech Info Plus.21 historian. The site historian is required to have capacity for 1000 additional tags.

Key benefits include: Steam Stations 3 can benefit from existing MES and SAP system investments.

f) Material Reconciliation

Currently Steam Stations administrators are collecting data into spreadsheets where daily, monthly and yearly material reconciliation is performed before data is uploaded into SAP PP. The Steam Stations require a material balance that will allow major and minor mass balances. Minor mass balances are required around Utility equipment such as boilers, turbines, demineralisation units and compressors. Major material balances are required around Steam Stations 1, Steam Stations 2 and Steam Stations 3. Once reconciled the raw material consumptions of oil, boiler feed water, coal and electricity as well as the final production values are required to be automatically uploaded to SAP on a daily basis. This Bill of Materials is found in Appendix L, Table L-7. These values need be evaluated by the Production Administrator and Material Requirements Specialist before writing the values to the SAP system on a daily per batch basis.

Key benefits include: Efficient data collection and reconciliation of the bill of materials. This system will also allow for the detection of instrument errors as noted by the deviation from previous values and therefore steam stations customer interface will improve.

g) Production Log Management

A requirement was captured for a system to capture production logs. The shift manager, process technician and production manager will review these comments to monitor process performance and process conditions during production events. The production logs will facilitate communication and also a smooth shift hand-over which can assist with analysing and understanding the plant performance during the review cycle, see Appendix L, Figure L-3. The main filters used to display logs are:

- Current situation
- Instruction
- Information
- Incident
- Site Info

The current situation filter should be the default view showing all logs in chronological order. Production log sheet access is required to be role based. The user rights is determined based on the user profile which is assigned based on three groups of users i.e. process controllers, shift supervisors and management. New logs can be entered based on the rights assigned to the user; logs can be entered for criteria shown in Appendix L, Table L-3. If the user chooses criteria 1-4 a further classification should prompt the user to categorise logs according to the following criteria:

- General note
- Safety incident
- Maintenance notice

When the user has completed log input, the electronic log sheet should return to the default view which is the current situation filter. Standing Instructions will always be shown as a static display. The time for which the instruction is displayed must be determined by the manager. The instruction must be removed when time has expired. For standing instructions every user group has to read and acknowledge the information, the product manager requires the ability to track acknowledgements. The following are example of production log entries:

- Production Log: Boiler 1 has tripped increasing loads on boilers to make use of all available spare capacity.
- Instruction: Follow cutback plan until the steam pressures recovers.
- Safety Incident: None.
- Site Info: Boiler 1 has tripped.
- Maintenance info: Auto Thermal Reforming has scheduled for maintenance shutdown this week.

The production log should be role-based and the standard views for a process controller, shift manager, production manager and plant manager can be different and can support their day to day off information requirements. The following describes the access privileges granted to each user:

- Each process controller should be able to add his/her own notes during a shift. The notes can be edited by the author but not other shift supervisors.
- The shift supervisor should be able to edit or comment on all the notes for a specific shift entered by different people.
- The plant manager should be able to comment on all notes for any shift.
- Notes are grouped per shifts and are time stamped.
- Notes are also associated with a specific person to keep track of the author and editor of a note.

Production logs must be displayed according to filters defined for log entry and navigation should allow a view of log entries relevant to the criteria and date and time period selected. Each Steam Stations is required to have independent production logs, a view of all the plants logs can only be viewed by Steam Stations management. The tool is required to be web based to ensure it is easily available to users. Alerts should be accessible to the shift supervisor and production manager when standing instructions are read by users. Approximately 40 users will require access, these include standby personnel and the roles are shown below:

- Production Manager
- Plant Manager
- Plant Engineers
- Shift Supervisor
- Process Co-coordinator/Process controllers

Key benefits include: This system will facilitate communication to the process controllers and will allow the ability to facilitate seamless shift handover. Production logs will be available to troubleshooting production events.

h) Plant Performance Management System

Currently Steam Stations 1 and 2 have Production Dashboards to act as an advisory system for process controllers to manage operations profitably. The system interfaces the process historian and SAP system to report production Key Performance Indicators (KPI) in near real time. These include steam to steam to oil ratio, steam to coal, cost to produce a ton of Steam (R/ton Steam). Considering this process controllers are able to manage the Steam Stations operation profitably. These KPI are also aggregated into KPI such as boiler and plant conversion efficiency for management benefit and strategic decisions. This system is based on the Aspen Tech Web.21 technology and the plant historian and SAP systems are used for source data. Steam Station 1 and 2 are enabled however Steam Station 3 does not have a system. Steam Station 3 would like to have system once the plant historian and based infrastructure is installed.

However, the Steam Stations personnel require this system be integrated into the Production Log and accessible from the Operations Portal. In the case a process event is detected by this advisory system, the dashboard is required to push the event information automatically into the production log system. These events must be critical to avoid overload of production logs being captured. This interface happens without the operator being triggered and therefore enables the operator to manage events and at a later stage update the log with the remedial action taken during a production event.

Additionally, Appendix L, Section 5 shows the reports being generate by the Steam Station administrators using Microsoft Excel. Data is sourced data from the plant historian and from other spreadsheets. These reports require enablement via an automated reporting system and this reporting system is required to interface to the central MES database and plant historian.

Key benefits include: Reduced effort to capture data and an accurate reliable reporting system to enable strategic and operational decisions. Information from the production event logs and reports will be reviewed in morning meeting.

4.7.2. Steam Stations Maintenance Systems

a) Maintenance Strategy System

The Steam Stations maintenance team require a system to assist in defining, communicating and implementing overall action strategies around assets. The system must facilitate reliability centred maintenance and failure modes and effects analysis. The tool must be able to manage asset strategies thereafter load them into SAP Plant Maintenance (PM). All master data should be transferred to SAP via an automated integration mechanism and task sheets should be populated as specified by Maintenance Strategy. The system must be the basis from which Maintenance Cost Management is done. It should provide the link to SAP Material Management and SAP Financial Management systems to enable effective cost tracking.

Key benefits include: Reliability centred maintenance will be automated and the interface to SAP will be automated increasing data integrity and reducing effort.

b) Maintenance Inspections

The current inspection process is enabled by entering all equipment conditions and notifications onto a Microsoft Excel spreadsheet. The notifications are then reviewed by the Maintenance planners before being entered into SAP Plant Maintenance (PM). Steam Stations require an inspection system to assist in identifying work thereby better enabling the adherence to safety requirements. A bar code label must be attached to critical capital equipment, to keep accurate account of the location and condition of such equipment. This asset tag will ensure that all labour and material is charged to the right asset when doing maintenance.

Inspection technologies are required where handheld mobile equipment with barcode scanners can be used in the plant inspection walkabouts to examine equipment and track work order status. Once the handheld is docked the data is downloaded to docking stations which can then push the data to SAP PM. These handhelds computers are also required to capture work order status and work feedback. This system is in operation at Sasolburg site however, Steam Stations are not part of this installation. The Steam Stations equipment is required to connect to the same application server, however this existing application server. Also an automated interface between the inspection system application server and SAP PM is required to minimise errors and time consumed when transferring data to Microsoft Excel then to SAP via a flat file.

Key benefits include: automatic upload on inspection notifications ensuring that maintenance planners workload is reduced. This system will increase data integrity and reduce effort.

c) Enhancement to Maintenance Reporting

Steam Stations require reports that can be generated by the maintenance strategy and maintenance inspection software. Typically reports are shown in Appendix L, section 6. Key benefits include, increased visibility enabling improved decision making on asset strategies and maintenance performance.

4.7.3. Enhancement to Laboratory Information Management System

Sasol Infrachem Laboratory has 33 customers on the Sasolburg site and has accreditation for ISO 9001:2004; additionally accreditation for ISO 9001:2008 is now being attained. The Steam Stations don't perform any sample tests except for preliminary tests on coal and demineralised water quality. The Steam Stations require visibility of sample testing status. This requires that samples collected must have a bar code label attached to ensure they are tracked. Although this is a mandatory system requirement it is less critical than the production and maintenance requirements.

Key benefits include: increased visibility of sample testing process.

4.7.4. MES considered for Improvement

Table 4-8 shows the selection considerations for mandatory MES selected for optimisation.

Table 4-8: MES Screening Criteria (Appendix H, Table H-7)

#	Criteria	Description	Weight %
1	Business Readiness	The functional requirements will indicate business readiness and people readiness and eliminate a technology driven approach. Personnel must be involved in system design and change process.	25
2	Business Benefit is recognised	The system must achieve business benefit and a business case will be developed to ensure that value is achieved.	50
3	Existing system available in Sasolburg	The Sasolburg systems must be considered to confirm if there is there a similar technology in Sasol or Sasolburg site.	25
Total			100

Considering these criteria, Figure 4-13 shows the screening of each system.

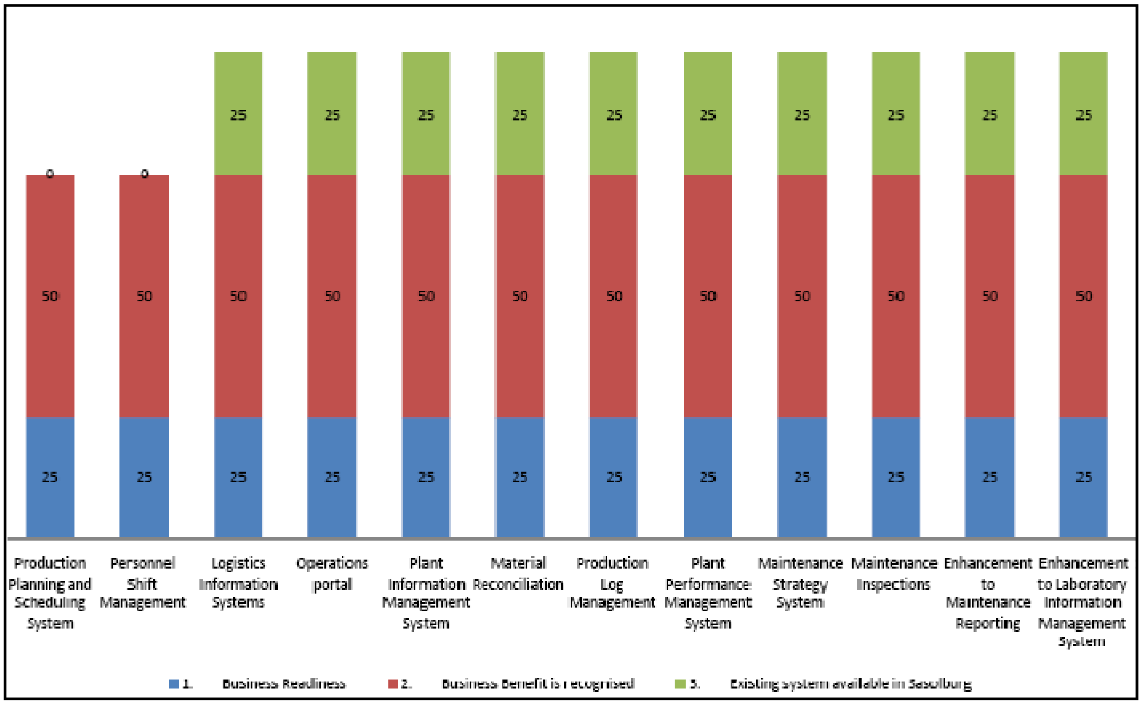

Figure 4-13: MES System Screening

Figure 4-13 shows that there are no existing systems for production planning and scheduling and personnel shift management systems to leverage from the Sasolburg local landscape. However, the screening criteria have not eliminated any of the mandatory systems on the basis of business readiness or business benefit. Therefore, to proceed with each initiative the Steam Stations require a business case, and a critical next step is a comprehensive cost benefit analysis and detailed solution design.

4.8. Conclusions

Considering the methodology described in Chapter 3, Chapter 4 has focused on the functional reference architecture and IT considerations development and application to optimise MES at the Sasol Steam Stations. Preliminary opportunities were identified to improve the manufacturing processes and MES. These opportunities were investigated and the resulting functional requirements were classified according to criticality. Thereafter conceptual designs were proposed and key considerations were centralised IT architecture with a practical view of leveraging the Sasolburg site MES installations. Considering the requirement selection criteria 12 of the 20 manufacturing systems were identified for improvement. As a result, Chapter 5 will discuss the findings of Chapter 4 within the context of the literature, draw the research final conclusions, highlight the research implications and limitations and bring about some ideas for future research.

5. CONCLUSIONS AND IMPLICATIONS

5.1. Introduction

This research report has been organised into five chapters which were structured, unified and focused on solving a research problem. The first chapter set the scene by introducing the research problem. Chapter 2 identified research issues and motivation for the problem being investigated and discussed these considering the relevant body of knowledge. Then, Chapter 3 focused on the approach and methodologies used to answer the research question and hypothesis developed in Chapter 2. Consequently, Chapter 4 demonstrated this approach in a case study at the Sasol Steam Stations. Finally, Chapter 5 briefly summarises the previous chapters and then, prior to making conclusions about the research, it explains how the chapters fits together.

5.2. A Brief Overview of Previous Chapters

Chapter 1 provided a clear statement of the research problem being investigated **“How can Manufacturing Execution Systems (MES) be optimised using a reference architecture developed from standards?”** Considering the body of knowledge, manufacturing enterprises are seeking MES to address the challenges of integration and interoperability between plant floor and business system (Boucher and Yalcin, 2006, Morel et al, 2003). MES offer benefits which include data transparency for decision making, reduction in time wastage, reduction in administration expenses, improved customer services, improved quality, early detection systems and real time cost control. These benefits lead to increasing employee productivity and compliance with directives (Meyer et al, 2009). Considering the research problem, Chapter 2 had posed three hypotheses based on the following key questions: “How to develop reference architecture from standards?”, “How to apply the reference architecture to gain benefits of process standardisation and shorter implementation time?” and “How to use the reference architecture to optimise MES and gain benefits?” Considering these this section summarises the motivation for these hypothesise.

Enterprise integration facilitates interaction between sub systems so that a common objective is achieved. Enterprise integration can be at a business level, functional level (via business processes), application level (via software systems) or hardware level (via computer networks) (Chen. et al, 2008). Integration is achieved by interoperability where interoperability is the ability for two systems to understand one another and to use functionality of one another (Panetto, 2007). Considering the manufacturing functions and information flows between each function, enterprise projects mainly rely on heuristics to guide design. However, reference architectures are required to efficiently guide the design of integration projects (Chelmeta, 2001, Williams T.J, 1991). The reference architectures introduce reusable design constituents such as functional requirements and IT architecture considerations (Boucher and Yalcin, 2006, Meyer et al, 2009, Bo and Zhenghang, 2004). This led to the first hypothesis; MES enable integration and interoperability between plant and business systems however, functional reference architecture is required to guide MES optimisation. .

Furthermore, MES standards are being used within a manufacturing company is to describe the information flows between the plant and business systems (Morel et al, 2003). Therefore, the ISA S95 and OAGIS are considered a good starting point for conducting the necessary baseline analysis of a company's specific business process flows (MESA 25, 2007). However, IT architecture considerations are required to ensure MES are efficiently designed (Liu, 2002 and Meyer et al, 2009). This led to the second hypothesis; functional and IT reference architectures derived from standards and authoritative guidelines is required to ensure that MES optimisation progresses from a well defined, reference architecture..

In addition, the execution of an MES integration project is complex and often extended due to organisational and human considerations (Chalmeta, 2001). Therefore, a systematic approach and a formal methodology equipped with reference architectures is required to facilitate a common understanding and also reduce the analysis and design phases of a project (Chalmeta, 2001 and Cheng et al, 2001). This led to the third hypothesis; considering human and organisational factors, MES optimisation requires a formal methodology and systematic approach to ensure a common understanding and integrated approach.

Therefore, the execution of an MES integration project is complex and therefore Chapter 3 has suggested methods to proceed based on the body of knowledge. This research report has used an interoperability framework adapted from Daclin et al (2006) and Boucher and Yalcin (2006). Considering this approach, the reference architecture is required as input to the initial analysis phase and system design phases of the project (Daclin et al, 2006 and Meyer et al, 2009). This reference architecture must consist of business process models that should primarily adhere to the IDEF 0 modeling methodology (Daclin et al, 2006, Boucher and Yalcin, 2006). These business process models will be used to identify system requirements and optimisation opportunities. Subsequent to requirements elicitation the identified MES system optimisation opportunities will be understood and the ensuring MES system design will require considerations from key components of the IT architecture (Liu, 2002 and Meyer et al, 2009).

The Sasol Utility plants were selected as a case study to apply the methodologies in Chapter 3 and Chapter 4 has presented the results of the research. The MES functional reference architecture was developed using a Sasol defined methodology which was aligned to the IDEF 0 methodologies. The functional architecture consisted of 3 level 1 processes, 24 level 2 processes and 94 level 3 processes. The architecture was applied using toolsets to identify improvements to the Steam Stations Production and Inventory, Maintenance and Quality manufacturing processes and 12 of the 20 manufacturing systems were selected. The following section will discuss the implication of Chapter 4 results in more detail.

5.3. Conclusions about the Hypothesis and Research Questions

In this section, the results presented in Chapter 4 will be compared with literature for confirmation, if the results are not confirmed than the reasons are discussed. These results are discussed considering each hypothesis of Chapter 2.

5.3.1. First Hypothesis

“MES enable integration and interoperability between plant and business systems however, functional reference architecture is required to guide MES optimisation.”

Manufacturing enterprises deploy a host of advanced manufacturing technologies to enable the plant to business systems integration. Therefore the requirement for standardisation and improved enterprise integration between plant and business systems has motivated this research. This research report has developed and applied functional reference architectures to coordinate design of MES (Gorbach, 2004 and Boucher and Yalcin, 2006). The reference architecture was developed using the Sasol business process modeling methodology which is aligned to the IDEF 0 methodologies, also this architecture can be reused at other similar manufacturing operations (Boucher and Yalcin, 2006).

5.3.2. Second Hypothesis

“Functional and IT reference architectures derived from standards and authoritative guidelines is required to ensure that MES optimisation progresses from a well defined, reference architecture.”

This research report has assessed the most relevant MES standards identified as the ISA S95 and OAGIS (Meyer et al, 2009 and MESA 25, 2007). These standards were applied in developing the functional architecture used to design MES according to standardised functional requirements and data flow models (Chen D and Venadat F, 2008). Consequently, the functional requirements process was concise because a common understanding was created prior to requirement workshops (Williams T.J., 1991, Meyer et al, 2009). Therefore, the Steam Stations MES maturity was assessed based on the business processes and enablement opportunities. Also, IT architecture considerations were used to categorise systems and identify systems that were at risk as they were not being suitably managed (Liu, 2002, Meyer et al, 2009).

5.3.3. Third Hypothesis

“Considering human and organisational factors, MES optimisation requires a formal methodology and systematic approach to ensure a common understanding and integrated approach.”

The research used a systematic approach and formal methodology and the following were key elements (Chalmeta, 2001, Boucher and Yalcin, 2006):

- a clear case study purpose was defined
- the workshop schedule was communicated
- workshop objectives and workshop information requirements was clearly defined

Also, the case study purpose was defined as follows: “This initiative is focused on improving the Steam Stations operational efficiently by investigating and proposing methods of optimising manufacturing executions systems including production and inventory, maintenance and quality activities.” This approach fostered a trust relationship and therefore assisted a successful requirements capturing approach. Additionally, the manufacturing processes presented in toolsets which created a reference to physical systems thereby creating an understanding of the possible to-be state.

5.4. Conclusions about the Research Problem

Based on the qualitative findings from this report the research question, **“How can Manufacturing Execution Systems (MES) be optimised using a reference architecture developed from standards?”** has been answered. The research report has shown that MES can be optimised using this functional architecture however, the following must be considered:

- Standards such as ISA S95 are a guideline for optimising MES; however the application requires an understanding of the manufacturing operation in concern.
- A systematic approach is required; however this approach must be supplemented by describing the functional architecture with identifiable MES.

5.5. Research Implications

This section provides the theoretical implications of the research and provides evidence of where this research can be practically reused.

5.5.1. Implications for Theory

Figure 5-1 shows the theoretical implications of this research and supports the fact that this research report has made a contribution to knowledge both in its immediate discipline and to the wider body of knowledge where other disciplines could benefit from its findings.

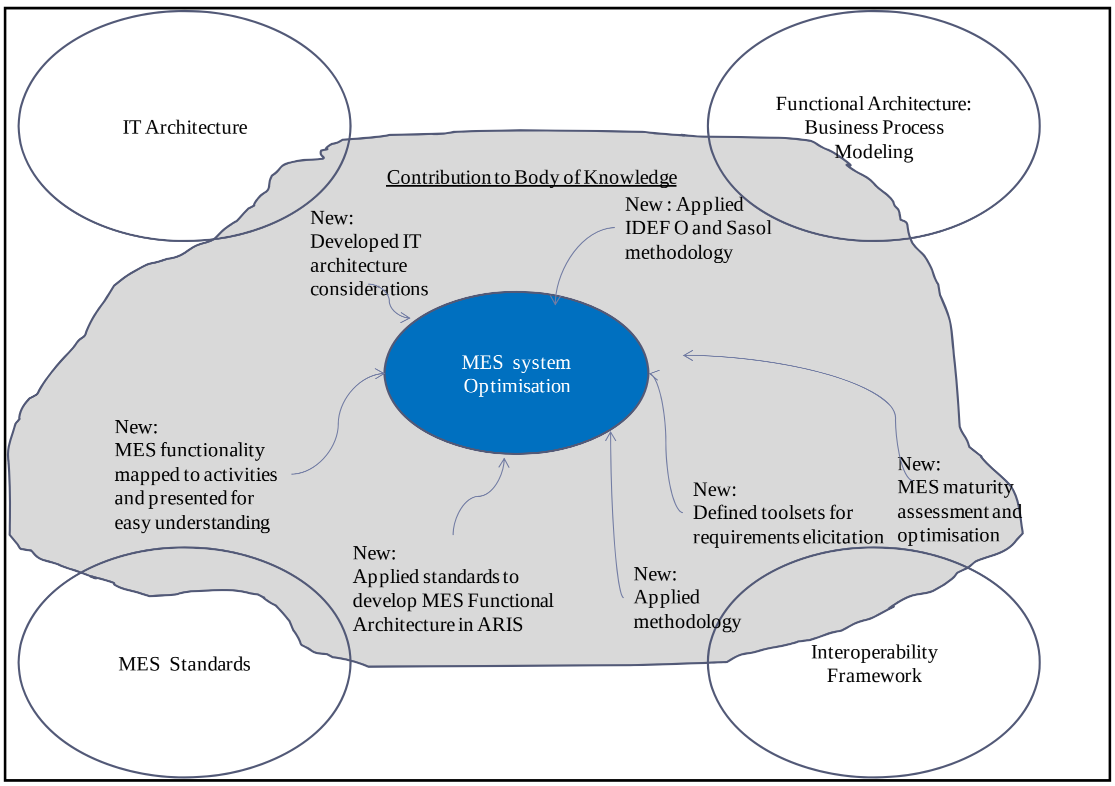

Figure 5-1: Contribution to Body of Knowledge

5.5.2. Implications for Practice

The research literature has shown that MES system optimisation brings benefits of vertical plant to business system integration. Considering possible MES benefits, the research findings have shown that the application of functional architectures developed from standards are required to facilitate the requirements capturing process and also identify opportunities for system optimisation. These reference architectures can be reused at other similar manufacturing operations. As a result, the approach to develop functional architectures from standards will become a wider area of study and in line with the new demands in MES technology development. Also, considering upstream and downstream Oil and Gas Supply Chain Systems, functional architecture development could facilitate horizontal enterprise integration. Also, the use of ISA S95 and other MES standards will promote functionality standardisation.

5.6. Research Limitations

The research report has aimed to develop functional reference architecture from standards and thereafter use this architecture to optimise MES. The architecture was developed specifically for Utility operations, specifically Sasol Steam Stations located in Sasolburg. Some of the research limitations, acknowledged by the author, which do not detract the significance of the report findings, refer to the inclusion of standards focused on MES applications in the horizontal supply chain. Also, the research did not consider the detailed application development and implementation methodology.

5.7. Further Research

This final section is written to help students and other researchers in selection and design of future research. From literature it has been seen that plant to business integration is seen as a major area where business benefit can be achieved and therefore MES technologies are being deployed. However, there are research gaps for optimising the horizontal integration problem. Finally, this research report showed that it is both theoretically and practically possible to find solutions to MES system design and optimisation.

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A. GLOSSARY

This glossary lists and defines the key terms used in the thesis.

- Attribute: Attributes are used to describe and define an object in more detail.
- Business Process: An end to end set of activities that are executed to achieve a desired business objective.
- Business systems or planning systems refer to system responsible for planning plant floor and manufacturing functions and activities, these are usually (Enterprise Resource Planning Systems (ERP) systems.
- A Brownfield operation refers to plants or systems that already existing.
- Connection: Connects two objects and indicates the relationship between the objects.
- Functional architecture is also a hierarchy of business processes. These business processes will represent a system or sub-system in terms of its structure and behaviour.
- Group: A Group is a logical directory in which models and objects are saved. It is similar to a folder in Windows. With the help of the Groups, the database is given a logical structure, and can be arranged in a hierarchy with a number of levels. User access rights can be defined at Group level.
- Method: The method specifies the process, the standard and the conventions required to promote process mapping standardisation.
- Model: A graphical description of the business reality and represented by a model type depending on the level in the business hierarchy. When creating a model, it is always assigned to a certain Group.
- Object: An Object is a unique artifact saved in the database. It is described in more detail by its attributes.
- Plant floor systems also called manufacturing systems are defined as "The arrangement and operation of machines, tools, material, people and information to produce a value-added physical, informational, or service product whose success and cost is characterized by measurable parameters.",
- Process View: This view is the standard view in which processes are documented and viewed. This view represents the full set of processes applicable within a database for a Project, a Cluster or for the Baseline.

- Repository: A central place where data is stored and maintained. A repository can be a place where multiple databases or files are located for distribution over a network.
- Symbols: In the models the objects are displayed through their symbols.

B. BUSINESS PROCESS MODELING METHOD

This section provides a description of the Sasol ARIS Modeling method used in developing the functional reference architecture. ARIS is chosen as the business process modeling tool within Sasol and is a repository based system. Figure B-1 shows the modeling levels used to differentiate functional hierarchies.

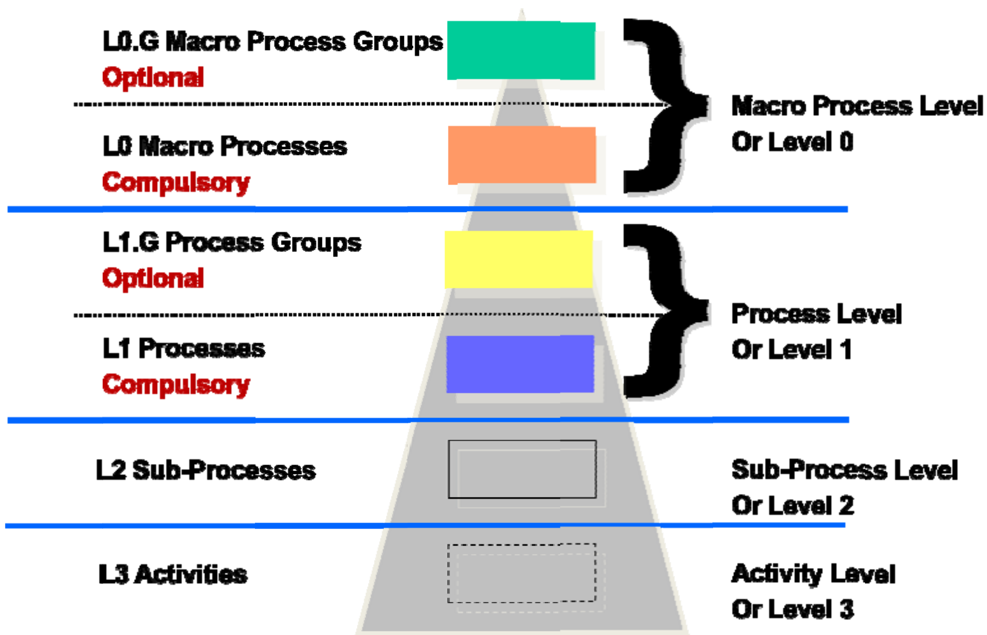


Figure B-1: Process Hierarchies

1. Value Added Chain Diagram

The Macro Process is the highest level of functional architecture business model; and facilitates drill down from top to bottom. Figure B-2 shows an example of steam stations Value Added Chain Diagram (VACD).

Table B-1: Macro Process

Level Definition	Model Types	Object Types
Macro Process Level 0	Value Added Chain Diagram	Value Added Chain Diagram

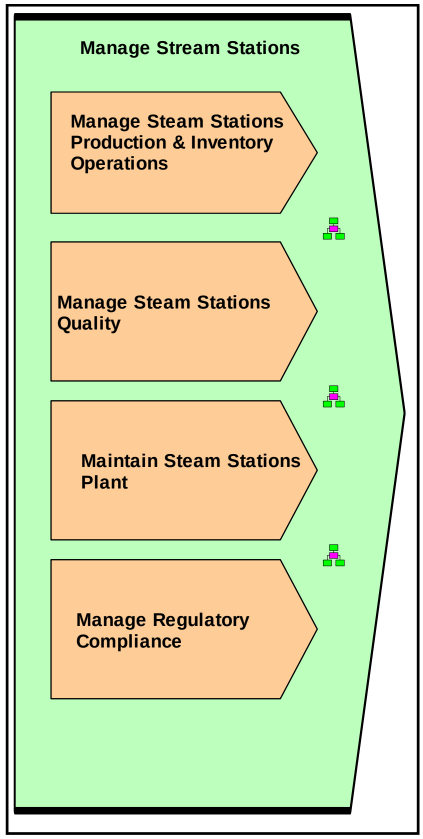


Figure B-2: Example of Value Added Chain Diagram

2. Macro Process Level – Level 1

Whereas the Macro Process level is the entry point to the business model the business processes are found in the drill downs below this level. Figure B-3 shows the Level 1 process which describes the manufacturing operation. This process may be adapted or changed to support changes in the business strategy.

Table B-2: Level 1 Process

Level Definition	Model Types	Object Types
Process Level 1	Value Added Chain Diagram	Value Added Chain Diagram
	Functional Allocation Diagram is assigned to VACD	Function Objective

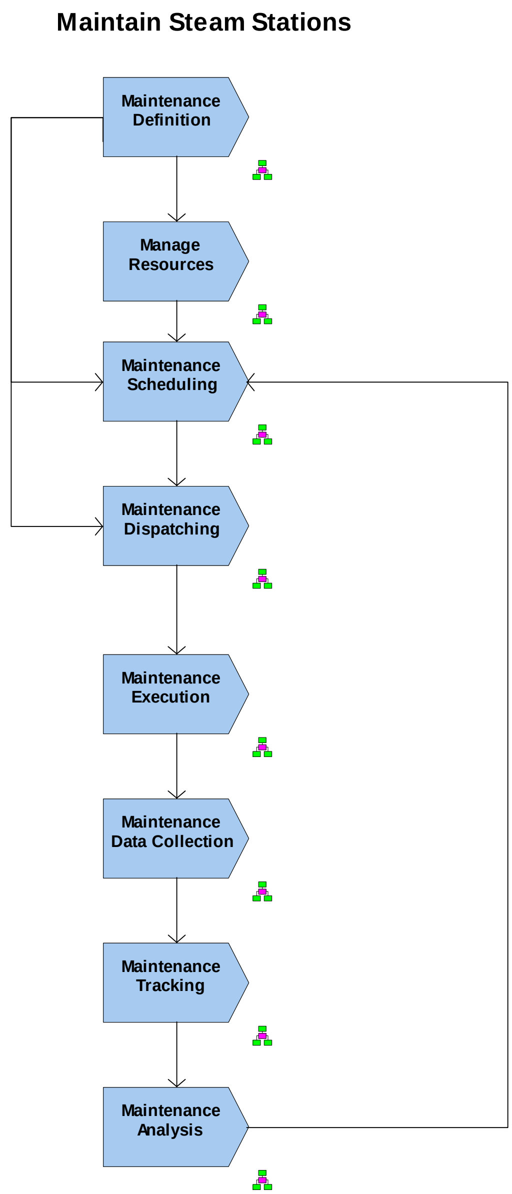


Figure B-3: Example of Level 1 Business Process

3. Sub Process Level – Level 2

On the Sub-Process level the modeling method is restricted to Lean Event Driven Process Chain (EPCs) with assigned Functional Allocation Diagrams (FADs), see below. However, if the process models become too big or cumbersome it is best practice to segment them by adding more Sub-Processes or by adding more detailed information to the functional allocation diagram.

Table B-3: Level 2 Process

Level Definition	Model Types	Object Types
Sub-Process Level 2	Lean EPC	Event Manual Function MES Function AND OR XOR
	Functional Allocation Diagram is assigned to VACD	MES Function Objective Control Person Type Risk

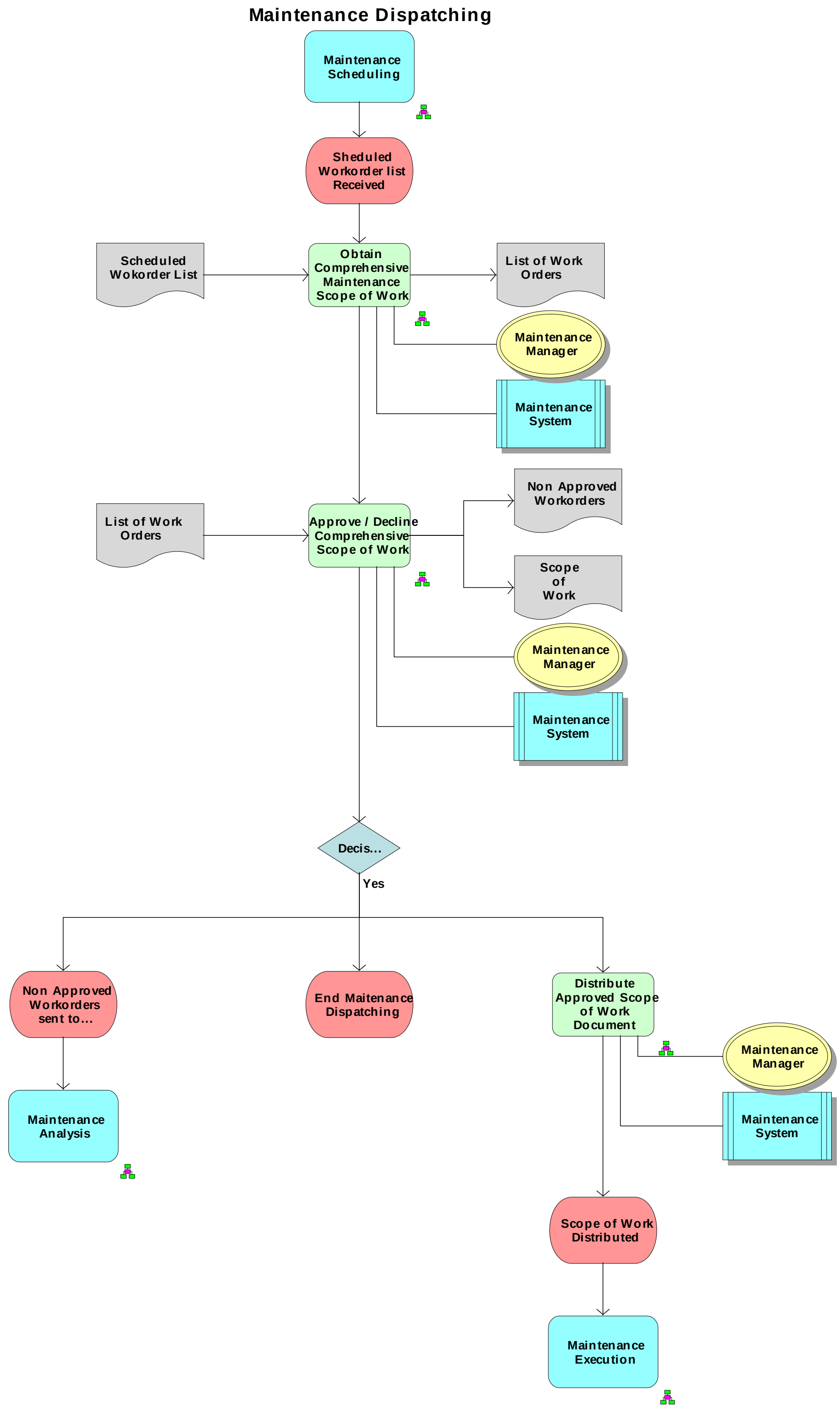


Figure B-4: Example of Level 2 Business Process

4. Level 3 Process - Activity Levels

Table B-4 shows the properties capture for level 3 processes.

Table B-4: Level 3 Process

Level Definition	Model Types	Object Types
Activity Level 3	Lean EPC	Event Manual Function MES Function AND OR XOR Process Interface
	Functional Allocation Diagram is assigned to VACD	MES Function Objective Control Person Type Risk Application system type Screen Attribute tables

Figure B-5 shows the level 3 process for activities in the model.

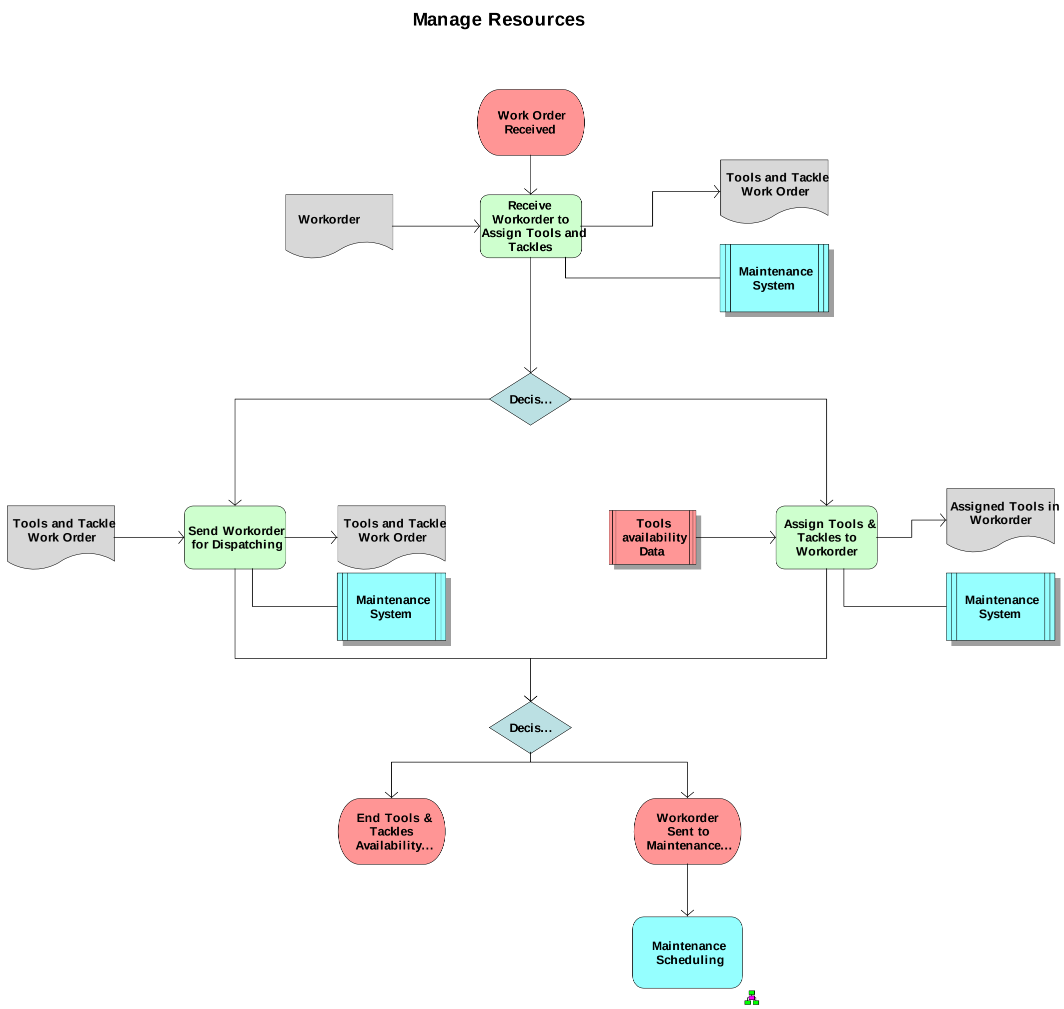


Figure B-5: Example of Level 2 Business Process

Figure B-6 shows the Functional Allocation Diagram (FAD) for an activity in the model.

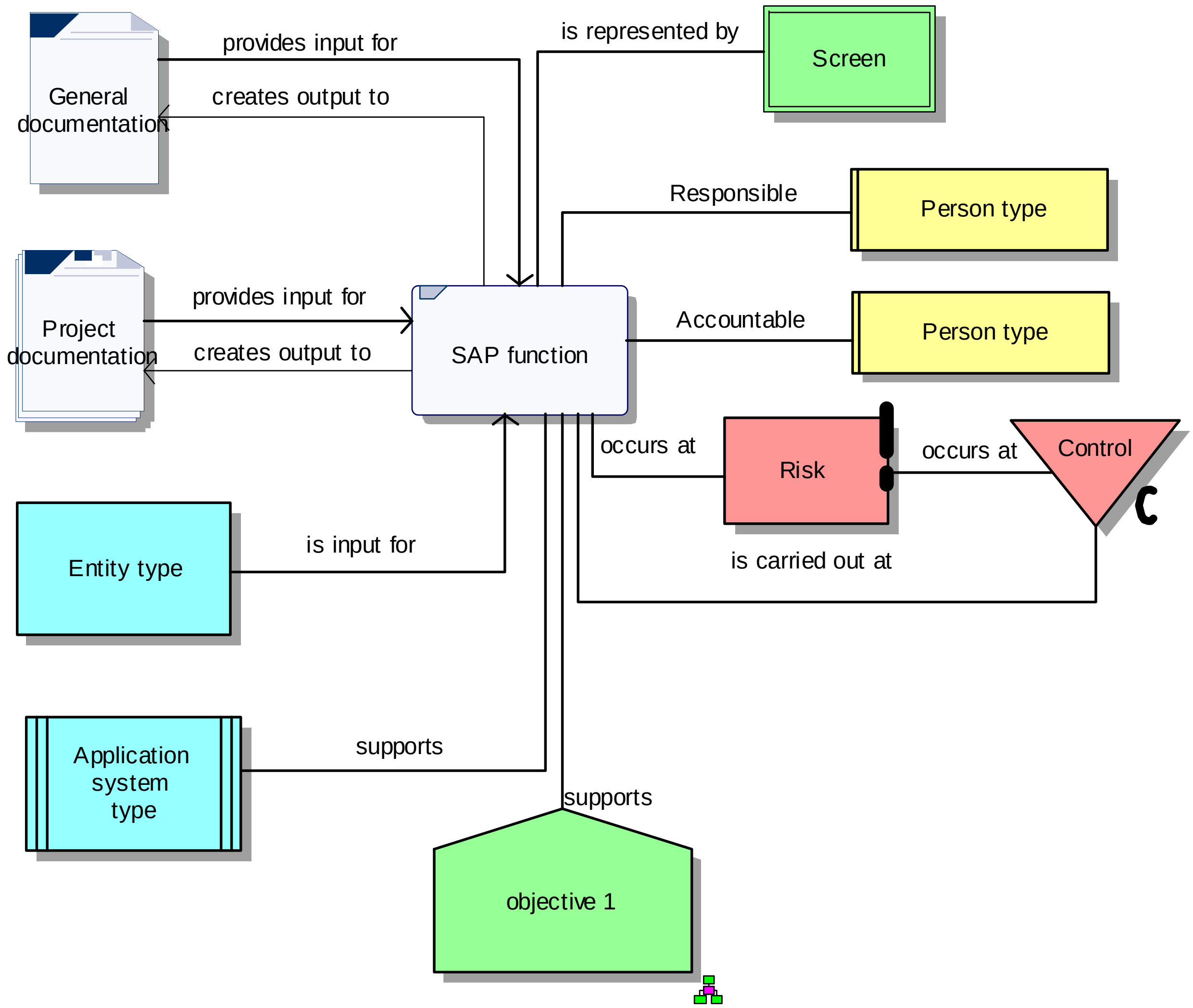


Figure B-6: Functional Allocation Diagram Example

5. Model Attributes

Name: The name of the object describing the Macro Process Group, the Macro Process, the Process Group or the Process. The name of the object should summarise what the function wishes to accomplish, preferably in the format of at least a verb plus a descriptive noun.

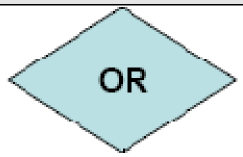
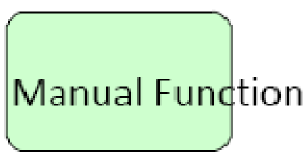
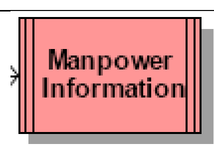
Description: A comprehensive description of the object is critical.

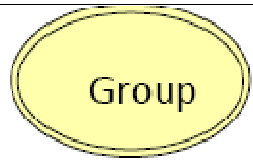
Process Owner: A process owner must be identified per Macro process and process. This is the person that should be consulted and approve all proposed changes to that specific process.

6. Objects used in modeling

The following table describes some objects used in modeling.

Table B-5: Objects used in Modeling

Object Appearance	Definition
	Indicates that one or more of the predecessor events should be completed before the successor function can be executed.
	Every process/scenario must start or end with an event object.
	A Manual function is an object representing a manual process or sub process on a higher level.
	A related process is a process that is required to be performed for a current process to achieve its objective.
	The document object represents a paper based document that forms part
	This represents a data cluster in this case containing Manpower information

	This is used to indicate positions of the same type.

C. KEY CONCEPTS OF THE ISA S95 STANDARD AND OAGIS

1. The ISA S95 Standard – Key concepts

The ISA S95 standard includes five parts, each of which covers particular aspects of the framework. Table C-1 describes each part in more detail.

Table C-1: ISA S95 Overview

ISA S95	Description
Part 1	Models and Terminology, defines the interface content between manufacturing functions and other enterprise functions
Part 2	The interfaces between manufacturing and business functions are considered, these are between levels 3 and 4 of the hierarchical model defined. The scope of Part 2 is limited to the definition of attributes for the Part 1 object models.
Part 3	Shows activity models and data flows for manufacturing information that enables enterprise and control system integration. The modeled activities operate between Level 4 planning functions and Level 2 process control functions.
Part 4	Consists of object models and attributes for Manufacturing Operations Management.
Part 5	Consists of business to manufacturing transactions.

1.1. Scheduling and control hierarchy

Figure C-1 shows the different levels of the ISA 95 functional hierarchy model. The model defines hierarchical levels at which decisions are made. The interface addressed in part 1 is between level 4 and level 3 of the hierarchy model. This is generally the interface between plant systems and enterprise systems (ANSI/ISA S95.00.01, 2000).

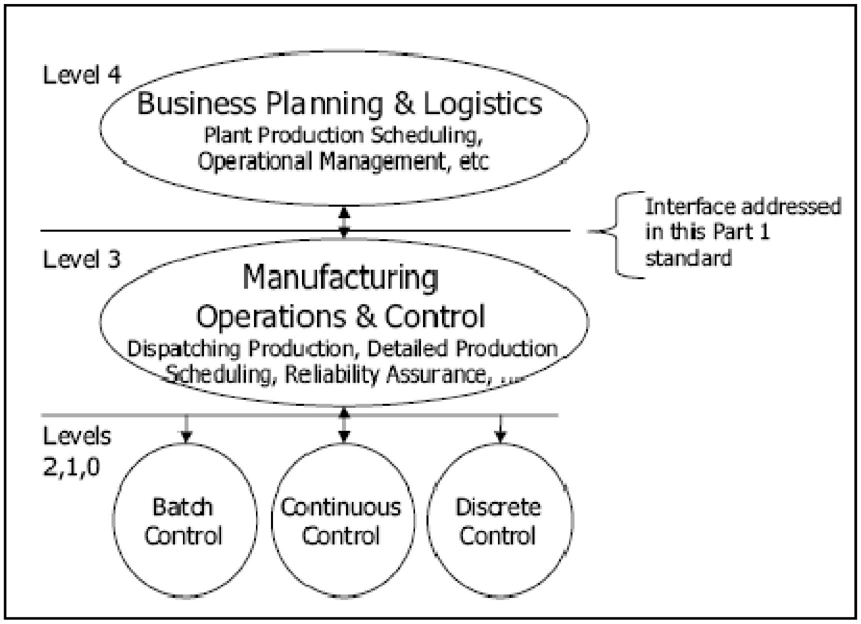


Figure C-1: High Level Functional Hierarchy (ISA S95.00.01, 2000)

Table C-2 below shows the functional interpretation of the activities at each level and the expected frequency of activities. This functionality applies to the continuous manufacturing processes.

Table C-2: Function Definition at each level (ISA S95.00.03, 2003)

Level	Functionality	Frequency
0	Measure, sense and monitor on-line the current state of variables such as temperature, pressure, flow etc. of process streams and equipment.	Continuous
1	Provide functionality such as process control and in order to maintain the process at safe levels. Maintain process variables at desired conditions. It includes real time visualisation of process values, short term trending, etc	Milliseconds Seconds
2	Provide the ability to operate a processing units at optimal point through the use of Advanced Process Control (APC) applications such as model predictive control etc.	Minutes Hours
3	Enable plant wide operations management with the ability to optimise the operations (production, maintenance, quality,	Hours Shifts

Level	Functionality	Frequency
	inventory), as well as operations performance management	Days Weeks
4	Provide the ability to plan and allocate resources to achieve corporate targets	Days Weeks Months Quarters

Considering the hierarchy of functions and equipment Table C-3 below shows the corresponding applications and systems that are deployed at each level.

Table C-3: Typical Systems and Applications Model

Functional Level	Software Application
4	Customer Relationship Management (CRM), Enterprise Resource Planning (ERP), Supply Chain Management (SCM), E-Commerce related applications
3	Manufacturing Execution Systems,
2, 1,0	PLC, DCS, SCADA

1.2. Equipment hierarchy model

The physical assets of an enterprise involved in manufacturing are usually organized in a hierarchical fashion as described in the Figure C-2 below. This model defines the areas of responsibility for the different function levels defined in the hierarchical model. The equipment hierarchy model additionally defines some of the objects utilized in information exchange between functions (ISA S95.00.01, 2000).

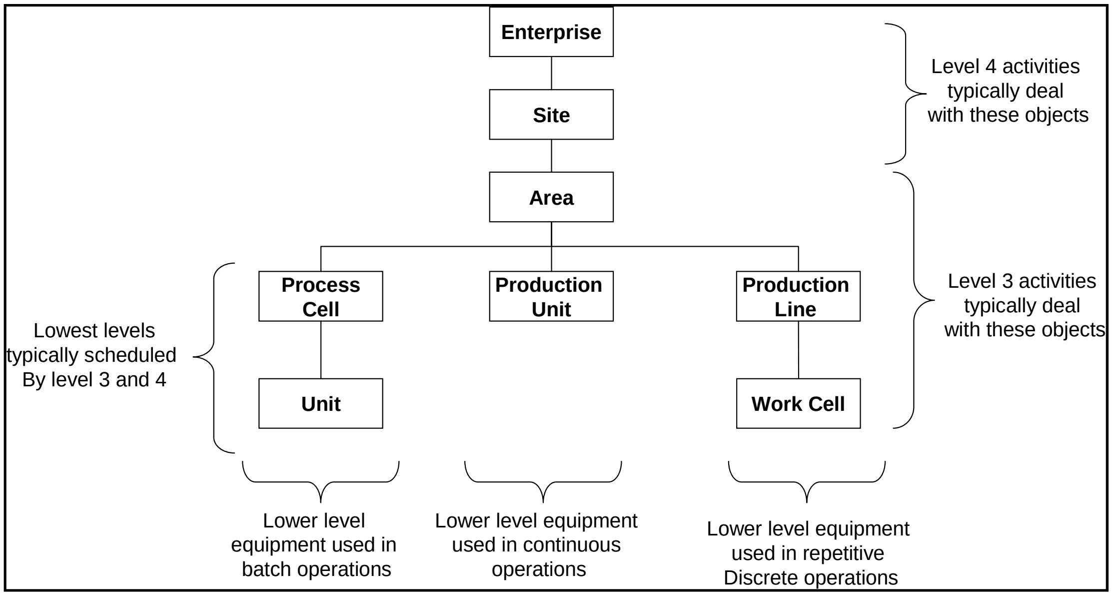


Figure C-2: Equipment Hierarchy Model (ISA S95.00.01, 2000)

1.3. Functional Data Flow Model

Manufacturing operations management (MOM) includes the activities of managing information about the schedules, use, capability, definition, history, and status of all of the resources (personnel, equipment, and material) within the manufacturing facility (ISA S95.00.03, 2000). Figure C-3 below shows the ISA S95 data flow model for Manufacturing Operations Management and is used to describe the plant to business interface (ISA S95.00.03, 2000). The model shows the functions of an enterprise involved with manufacturing and the information flows between the functions that and these information flow described the enterprise-control interface. The shaded areas in Figure C-3 are described as production operations management, maintenance operations management, quality operations management, and inventory operations management (ISA S95.00.03, 2000):

- The production operations management model includes the activities of production control (3.0) and the subset of the production scheduling (2.0) defined as operating as level 3 functions
- The maintenance operations management model includes the activities of maintenance management that operate as level 3 functions

- The quality operations management model includes the activities of quality assurance that operate as level 3 functions
- The inventory operations management model includes the activities of management of inventory and material including product inventory control (7.0) and material & energy control activities (4.0) defined as operating as level 3 functions

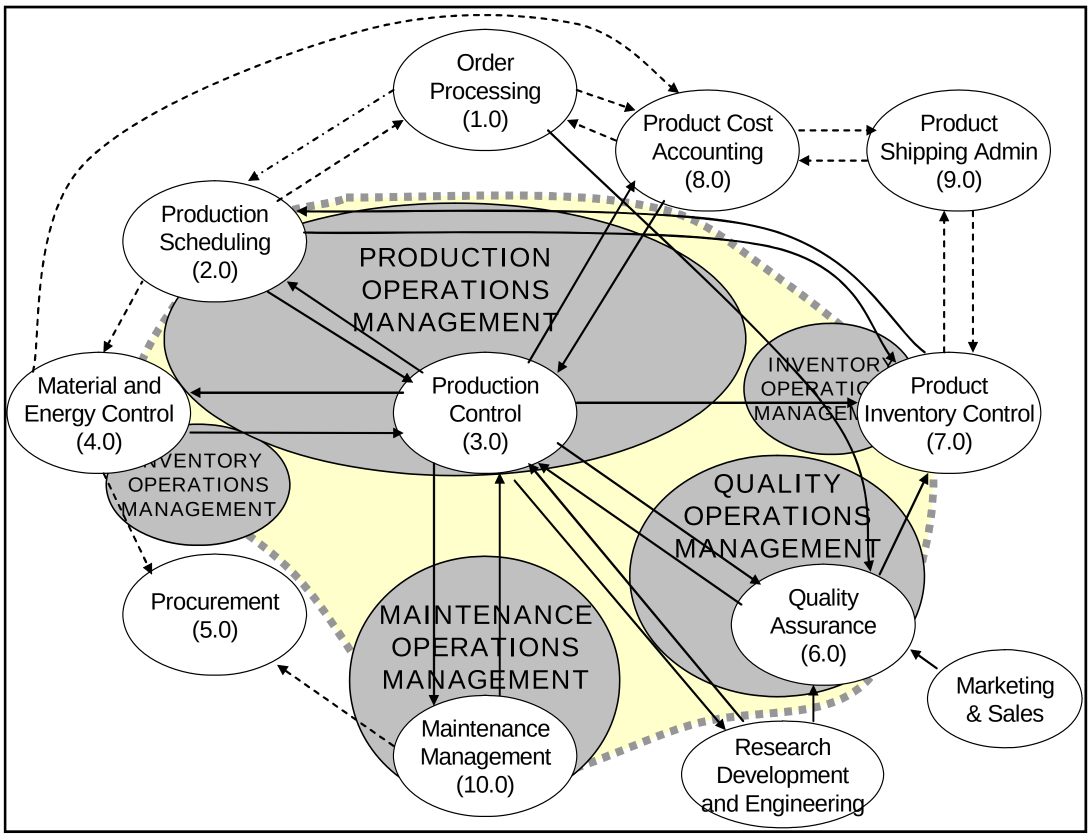


Figure C-3: MOM Model and Functional Data Flow Model (ANSI/ISA S95.00.03, 2000)

Considering the MOM model Figure C-4 shows the generic model used as a template to define the activities within the production operations management, maintenance operations management, quality operations management, and inventory operations management models (ISA S95.00.03, 2000, p. 24). This generic activity model applies at the activity level and provides a consistent framework for identifying and specifying data exchanges or touch points for the manufacturing operations. The general activities in production operations management are listed in the Part 1 standard and include (ANSI/ISA S95.00.03, 2000, p.29)**:**

- Reporting on production including variable manufacturing costs.
- Collecting and maintaining data on production, inventory, manpower, raw materials, spare parts, and energy usage. Performing data collection and off-line analysis as required by engineering functions. This may include statistical quality analysis and related control functions.
- Performing needed personnel functions, such as work period statistics (for example, time, task), vacation schedule, work force schedules, union line of progression, and in-house training and personnel qualification.
- Establishing the immediate detailed production schedule for its own area accounting for maintenance, transportation, and other production-related requests.
- Locally optimizing the costs for individual production areas while carrying out the production schedule established by the Level 4 functions.
- Modifying production schedules to compensate for plant production interruptions that may occur in its area of responsibility.

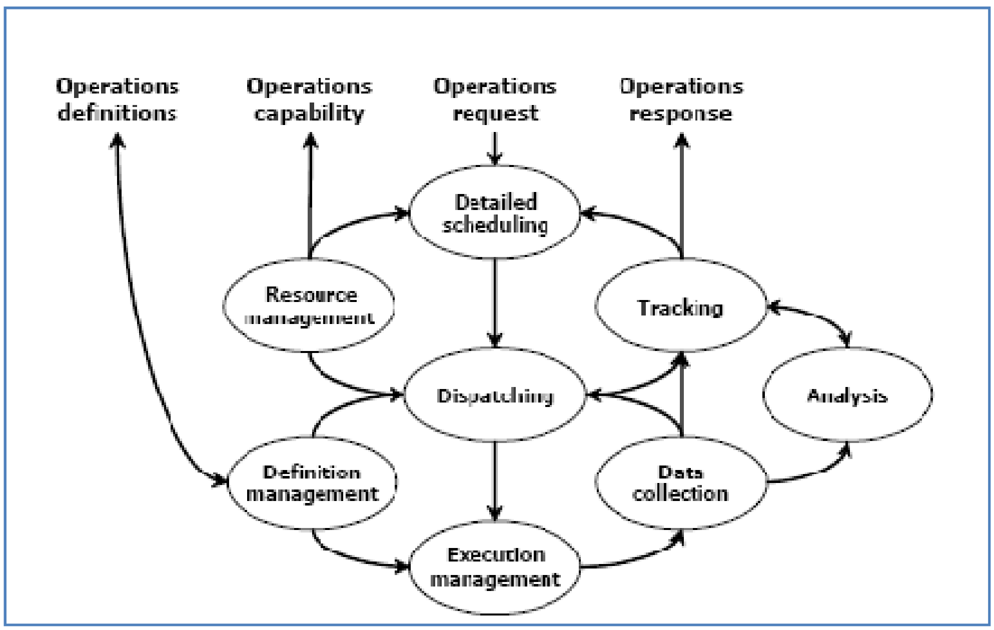


Figure C-4: Generic Activity Model of MOM (ISA S95.00.03, 2000, p.25)

Considering this Production Operations Management (POM) will be discussed in more detail. POM is be defined as the collection of activities that coordinate, direct, manage and track the functions that use raw materials, energy, equipment, personnel, and information to produce products, with the required costs, qualities, quantities, safety, and timeliness. Figure C-5 shows the functions found in the ISA S95 part 1 and shows the information flows between functions and where these have been described in the model (ISA S95.00.01, 2000, p. 78).

Data Flow Model Information	From Function	To Function	Object Model clause
6.2.1 Schedule	Production scheduling (2.0)	Production control (3.0)	7.5.1 and 7.5.2
6.2.2 Production from plan	Production control (3.0)	Production scheduling (2.0)	7.5.3 and 7.5.4
6.2.3 Production capability	Production control (3.0)	Production scheduling (2.0)	7.3
6.2.4 Material and energy order requirements	Production control (3.0)		Defined in terms of the Material Model, 7.3.4
6.2.5 Incoming order confirmation	Material and energy control (4.0)	Procurement (5.0)	Defined in terms of the Material Model, 7.3.4
6.2.6 Long-term material and energy requirements	Production scheduling (2.0)	Material and energy control (4.0)	Defined in terms of the Material Model, 7.3.4
6.2.7 Short-term material and energy requirements	Production control (3.0)	Material and energy control (4.0)	Defined in terms of the Material Model, 7.3.4
6.2.8 Material and energy inventory	Material and energy control (4.0)	Production control (3.0)	7.3.4
6.2.9 Production cost objectives	Product cost accounting (8.0)	Production control (3.0)	7.4
6.2.10 Production performance and cots	Production control (3.0)	Product cost accounting (8.0)	7.5.3 and 7.5.4
6.2.11 Incoming material and energy receipt	Material and energy control (4.0)	Product inventory control (7.0)	<Not detailed in object model>
6.2.12 Quality assurance results	Quality assurance (6.0)	Production control (3.0)	7.3.4.9 and 7.5.4
6.2.13 Standards and customer requirements	Marketing and sales	Quality assurance (6.0)	7.3 and 7.5.2
	Quality assurance (6.0)	Production control (3.0)	
6.2.14 Product and process requirements	Research, development, and engineering	Quality assurance (6.0)	7.4
6.2.15 Finished goods waiver	Functions Order processing (1.0)	Quality assurance (6.0)	<Not detailed in object model> Typically unstructured information handled on an ad-hoc basis
6.2.16 In-process waiver request	Production control (3.0)	Quality assurance (6.0)	Defined in terms of the Material Model, 7.3.4
6.2.17 Finished goods inventory	Product inventory control (7.0)	Production scheduling (2.0)	7.3.4 and 7.5.4
6.2.18 Process data	Production control (3.0)	Quality assurance (6.0)	7.5.3 and 7.5.4
6.2.19 Pack out schedule	Production scheduling (2.0)	Product inventory control (7.0)	7.5.2
6.2.20 Product and process know-how	Research, development, and engineering	Production control (3.0)	7.4

Figure C-5: ISA S95 Model Cross Reference

Considering this and applying the generic activity model ISA S95 describes each activity in the production operations management. Production execution management is defined as the collection of activities that direct the performance of work, as specified by the contents of the production dispatch list elements. The production execution management activity includes selecting, starting and moving those units of work through the sequence of operations to physically produce the product. The actual work (is part of the Level 2 functions (ISA S95.00.03, 2000, p. 30).

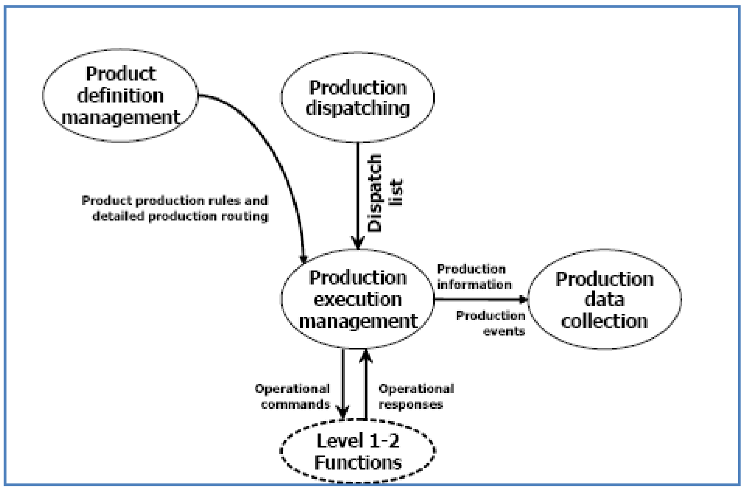


Figure C-6: Production Execution Management (ISA S95.00.01, 2000, p. 30)

The ISA S95 standard describes each process and activity within MOM in detail. These have been used to develop the business processes referred to as the functional reference architecture.

2. OAGIS – Key Concepts

The OAGI (Open Applications Group, Inc.) has developed a large number of business messages and integration scenarios for enterprise application integration and business-to-business (B2B) integration. The flows shown between the applications consist of OAGIS Business Object Documents (BOD's) that are defined as part of the standard.

Each BOD has a standard structure with a standard header and a body that is unique to the BOD (MESA, 25). Since June 2006, Version 9.0 of the OAGIS standard has contains 434

BODs that are reusable across integration scenarios and are constructed using reusable verbs (12) and nouns (77).

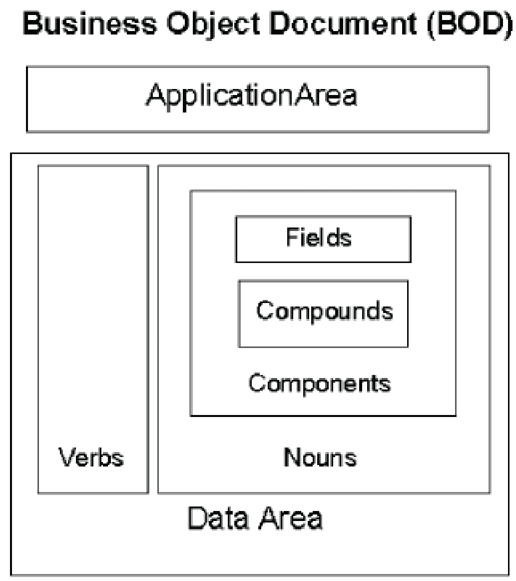


Figure C-7: Standard OAGIS BOD Structure

3. COMPARISON OF ISA S95 AND OAGIS

Table C-4 below shows a comparison of the ISA S95 and OAGIS.

Table C-4: Comparison of ISA S95 AND OAGIS (adapted from MESA 25, 2007)

	OAGIS	ISA S95
Focus	The standard does not clearly define process, tasks and activities. The focus is on the data interchange problem and includes Application-to-Application (A2A), Business-to-Business (B2B). The standard includes business process definitions called Scenarios and Business Object Definitions (BOD), to describe scenarios for	ISA-95 focuses on integrating business (Level 4) and plant (Level 3) operations domains and throughout plant operations, and models Level 3. Data exchanges are defined for the domains using models for activities, related functions and information objects.

	OAGIS	ISA S95
	data interchange.	
Data Model	OAGIS is focused on the data model for data exchange, not really for full enterprise objects. OAGIS uses XML to provide developers with a machine readable version of the data exchange data model.	ISA-95 provides a model of data objects for applications expressible in XML schemas, and exchanged between applications to coordinate MOM activities.
Messaging Support	The OAGIS BOD Message Architecture is independent of any information exchange mechanism. Each BOD contains one unique application interface to convey communication information at the integration layer.	Part 5 of ISA-95 defines a simple messaging scheme between data objects; each message consists of a verb and a noun describing the interface.
Extensibility	The BODs are extensible, while providing a common architecture and content for integration. OAGIS provides both user area extensibility and overlay extensibility. .	Using object properties in Parts 1 and 2, implementations such as B2MML use extension capabilities of ISA-95 properties through the use extension schemas.
Vendor Support	Implementations using OAGIS come originated from the ERP level 4 domain of expertise.	Providers of ISA-95 based implementations are mostly industrial automation system suppliers and plant floor system integrators.
Industry Focus	OAGi does know of over 200,000 business connections using OAGIS and perhaps over 1,000,000 in over 40 countries worldwide. Some of the largest users include IBM,	Solution providers and companies involved in manufacturing mostly. Other industries are Oil and Gas, chemical, aerospace and pulp

	OAGIS	ISA S95
	Microsoft recognise this standard.	and paper.
Availability	Specification is free.	A free download of B2MML is available at www.wbf.org. ISA standards series costs are available at a cost. .

D. MANAGE STEAM STATIONS PRODUCTION AND INVENTORY

The following section describes the functional reference architecture specifically for the production business process models. The figure below shows the Level 1 business process models. Each process model is composed of lean Event-Drive Process Chain (EPC) diagrams and Functional Allocation Diagrams (FAD's).

Model name	Model type	Group
Manage Steam Stations Production & Inventory Operations	Value-added chain diagram	Main group\Steam Stations Manufacturing Processes\Level 1

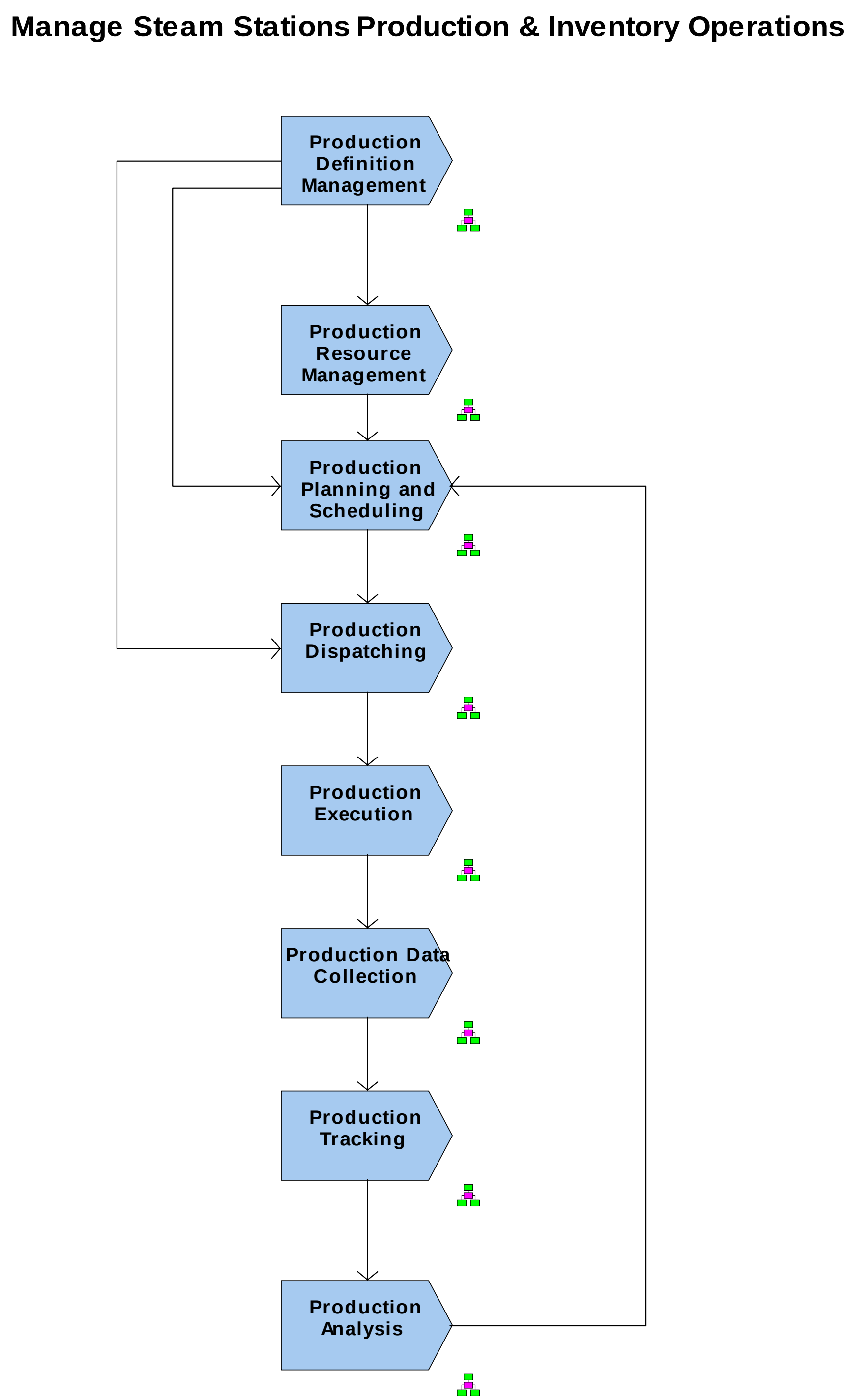


Figure D-1: Manage Steam Stations Production & Inventory Operations

Model name	Model type	Group
Product Definition Management	EPC	Main group\Steam Stations Manufacturing Processes\Level 2

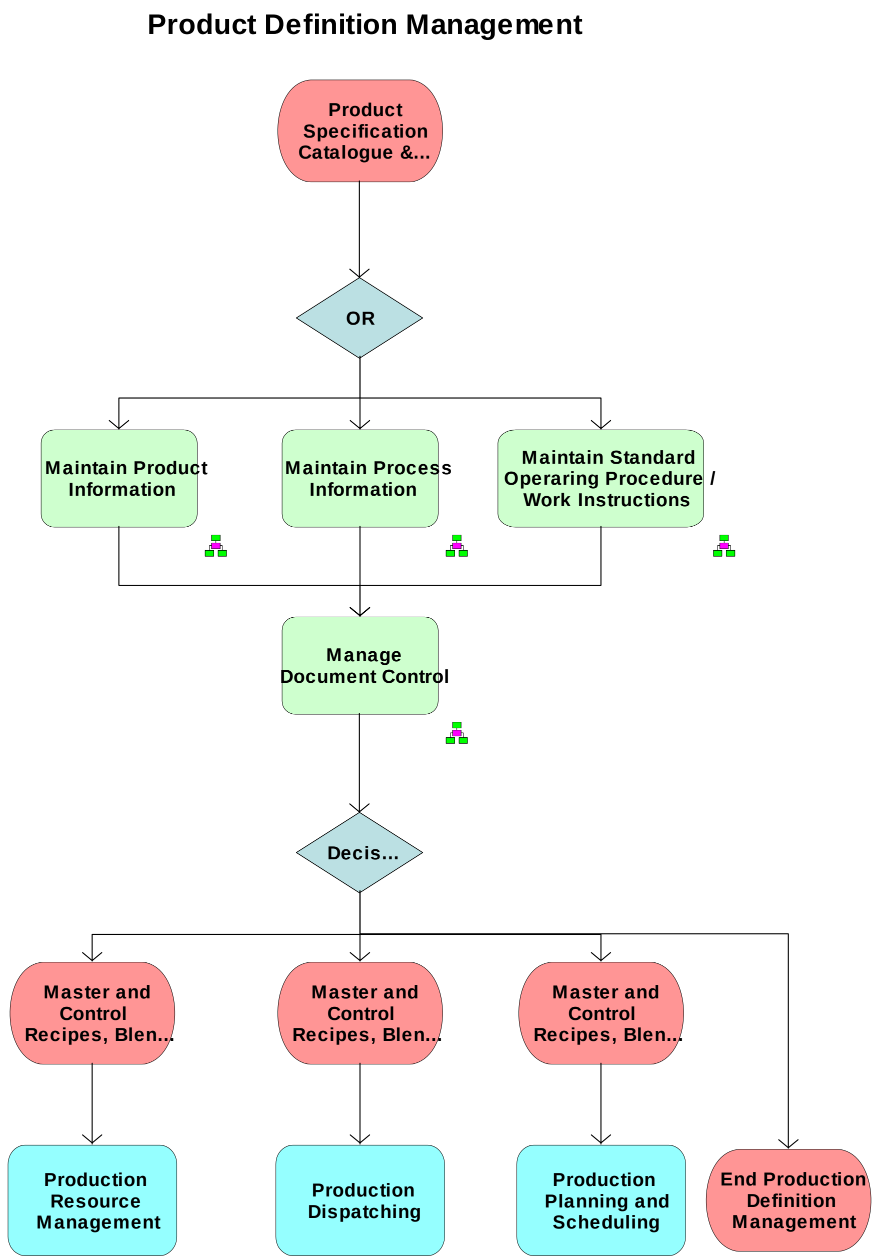


Figure D-2: Product Definition Management

Model name	Model type	Group
Production Resource Management	EPC	Main group\Steam Stations Manufacturing Processes\Level 2

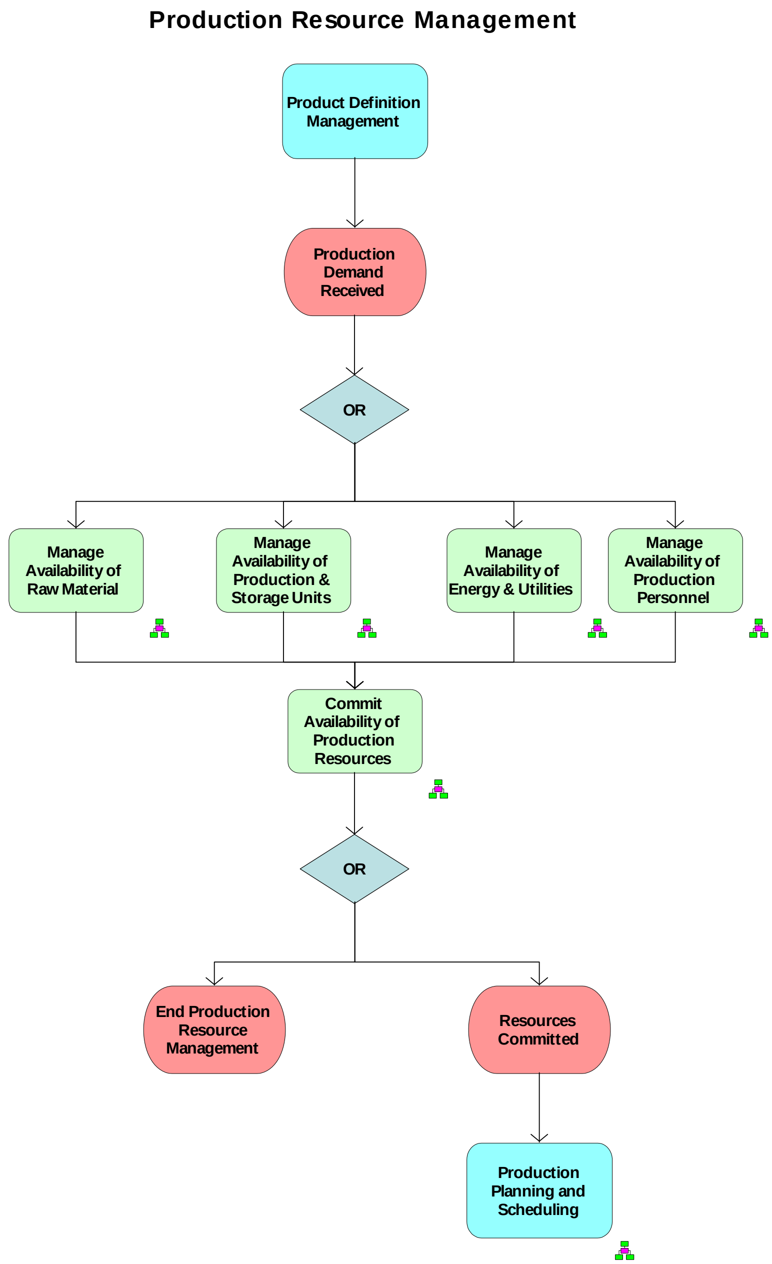


Figure D-3: Production Resource Management

Model name	Model type	Group
Detailed Production Scheduling	EPC	Main group\Steam Stations Manufacturing Processes\Level 2

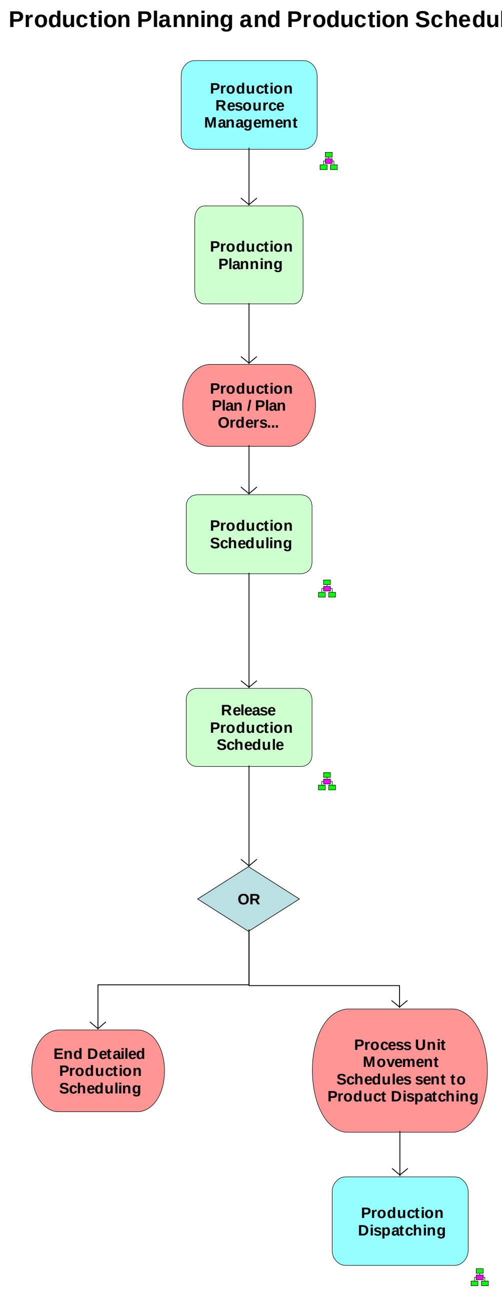


Figure D-4: Detailed Production Scheduling

Model name	Model type	Group
Production Dispatching	EPC	Main group\Steam Stations Manufacturing Processes\Level 2

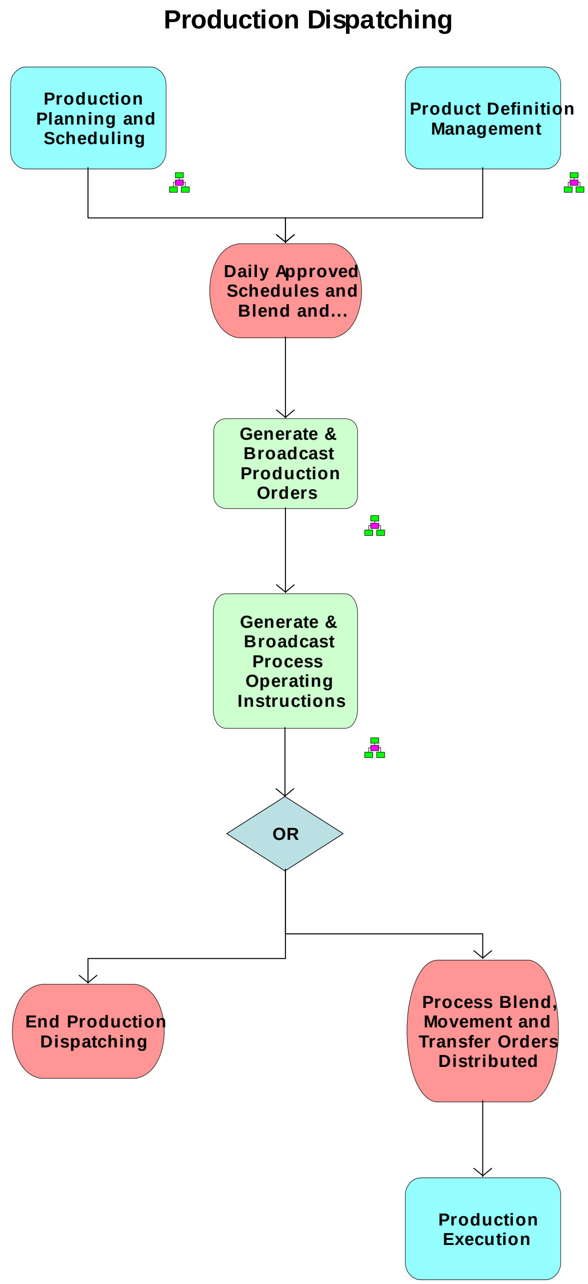


Figure D-5: Production Dispatching

Model name	Model type	Group
Production Execution	EPC	Main group\Steam Stations Manufacturing Processes\Level 2

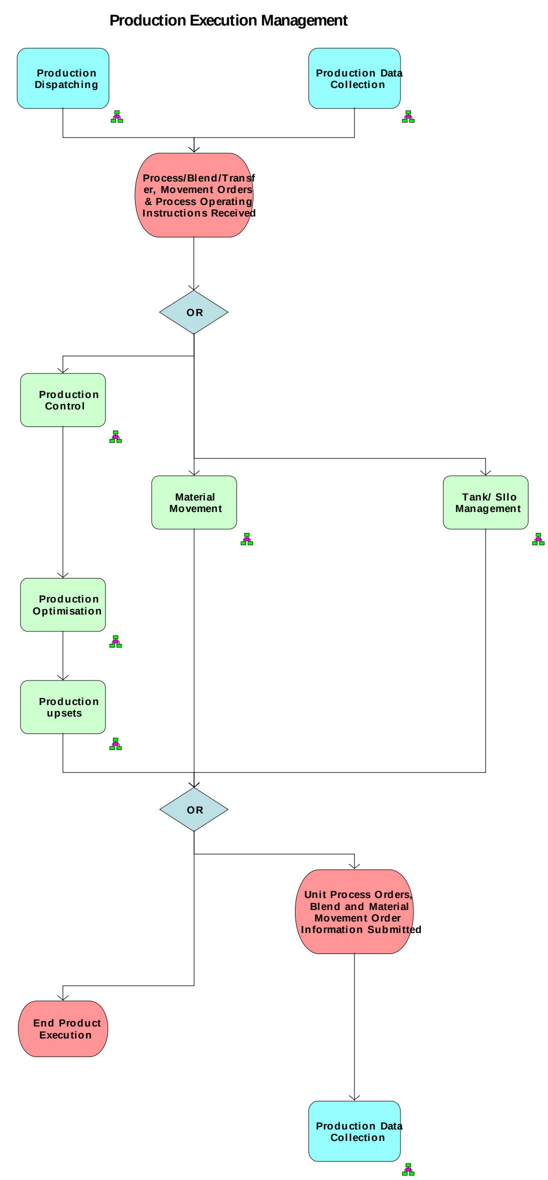


Figure D-6: Production Execution Management

Model name	Model type	Group
Production Data Collection	EPC	Main group\Steam Stations Manufacturing Processes\Level 2

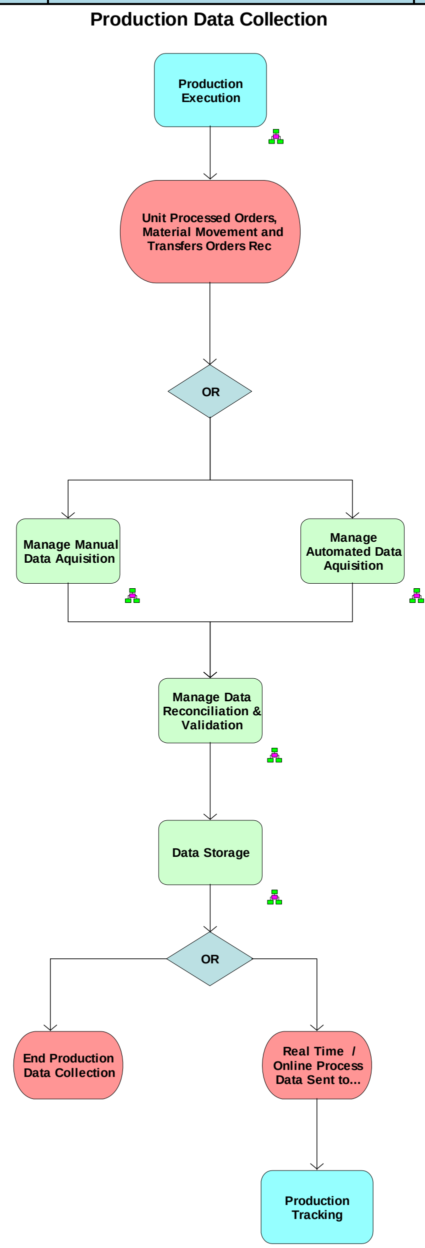


Figure D-7: Production Data Collection

Model name	Model type	Group
Production Tracking	EPC	Main group\Steam Stations Manufacturing Processes\Level 2

Production tracking

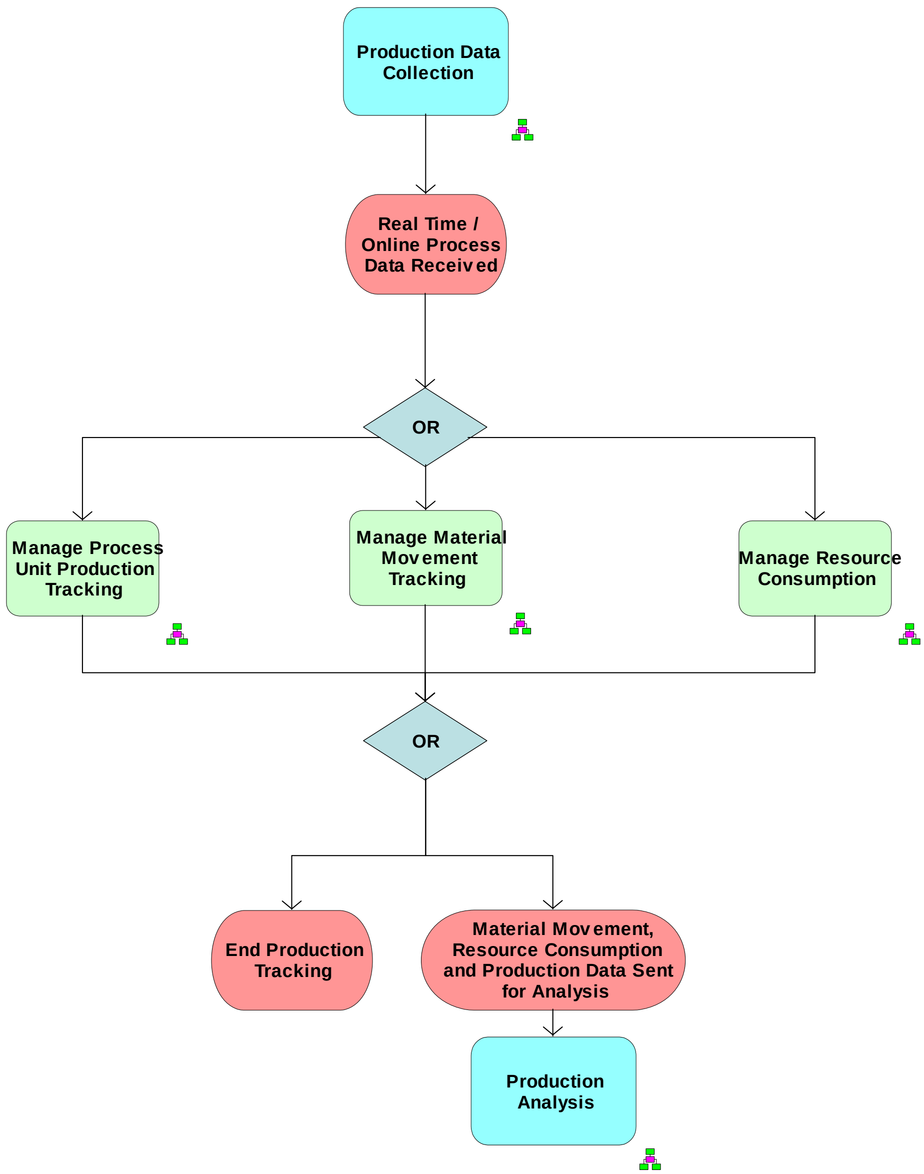


Figure D-8: Production Tracking

Model name	Model type	Group
Production Performance Analysis	EPC	Main group\Steam Stations Manufacturing Processes\Level 2

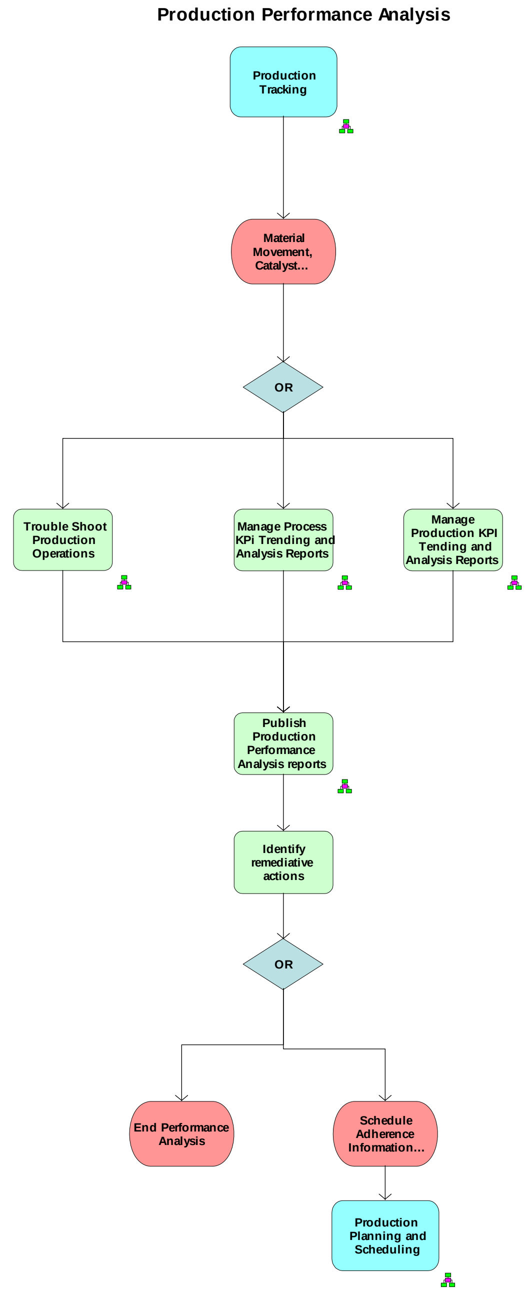


Figure D-9: Production Performance Analysis

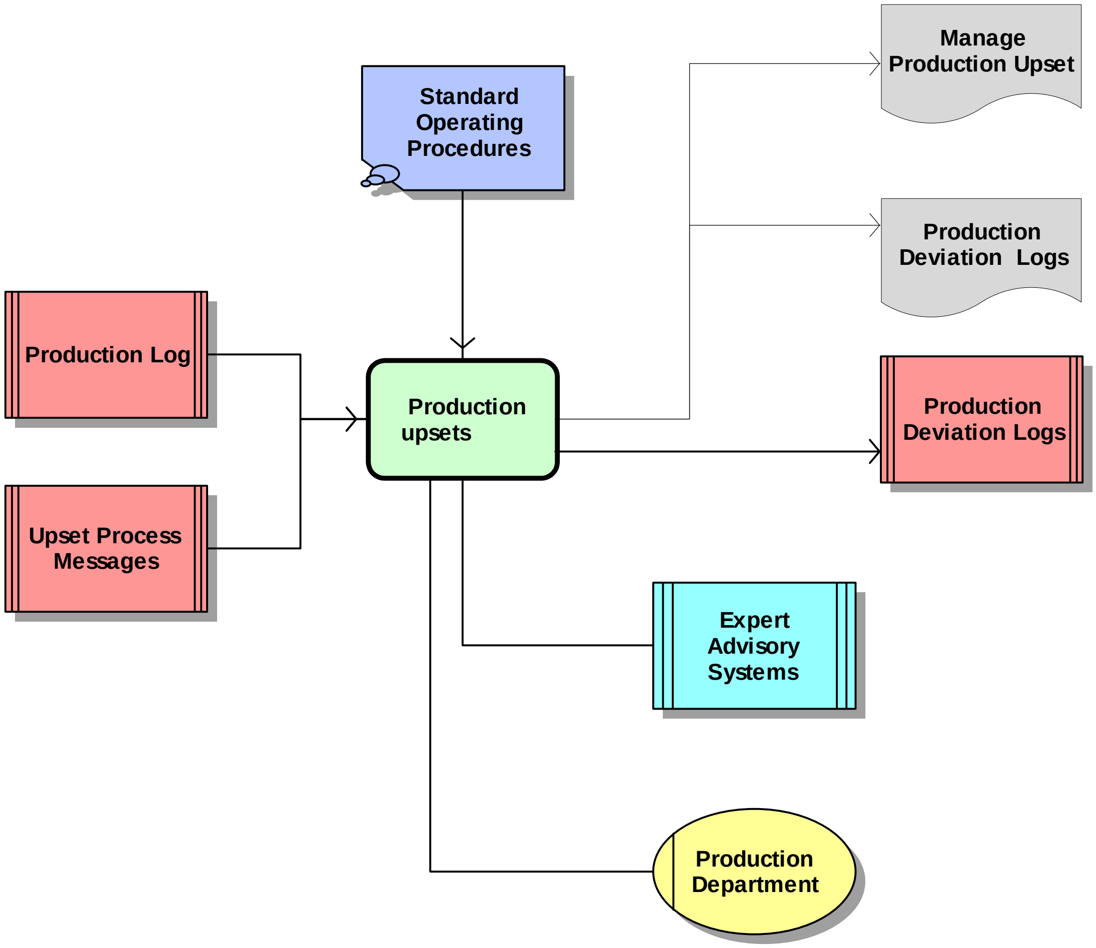


Figure D-10: Production Optimisation: Functional Allocation Diagram

Table D-1: Manage Steam Stations Level 2 Production and Inventory Processes

Model name	Model type	Group	Description
Manage Steam Stations Production & Inventory Operations	Value-added chain diagram	Main group\Steam Stations Manufacturing Processes\Level 1	
Product Definition Management	EPC	Main group\Steam Stations Manufacturing Processes\Level 2	Maintain product/production data
Production Resource	EPC	Main group\Steam	Management of all

Model name	Model type	Group	Description
Management		Stations Manufacturing Processes\Level 2	resources required to maintain production levels
Production Planning and Scheduling	EPC	Main group\Steam Stations Manufacturing Processes\Level 2	Alignment of the demand forecast with the production process to develop an optimized operations plan.
Production Dispatching	EPC	Main group\Steam Stations Manufacturing Processes\Level 2	Generation and broadcasting of production orders and instructions
Production Execution	EPC	Main group\Steam Stations Manufacturing Processes\Level 2	Production activities executed against agreed production plan and schedule.
Production Data Collection	EPC	Main group\Steam Stations Manufacturing Processes\Level 2	Manual and automated production information collection and archiving
Production Tracking	EPC	Main group\Steam Stations Manufacturing Processes\Level 2	Tracking of product production and materials movement
Production Performance Analysis	EPC	Main group\Steam Stations Manufacturing Processes\Level 2	Accurate on-time feedback on relevant production information enabling improved decision making.

E. MAINTAIN STEAM STATIONS

The following sections describes the functional reference architecture specifically the maintenance process models. The figure below shows the Level 1 business process models. Each process model is composed of lean Event-Drive Process Chain (EPC) diagrams and Functional Allocation Diagrams (FAD's).

Model name	Model type	Group
Maintain Steam Stations	Value-added chain diagram	Main group\Steam Stations Manufacturing Processes\Level 1

Maintain Steam Stations

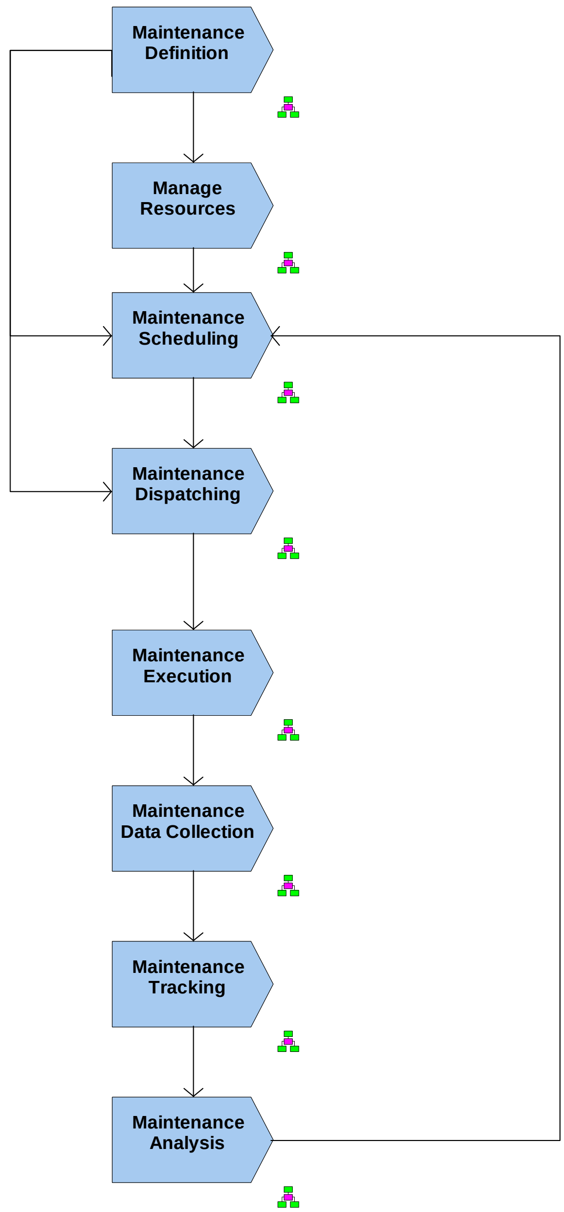


Figure E-1: Maintain Steam Stations

Model name	Model type	Group
Manage Maintenance Definition	EPC	Main group\Steam Stations Manufacturing Processes\Level 2

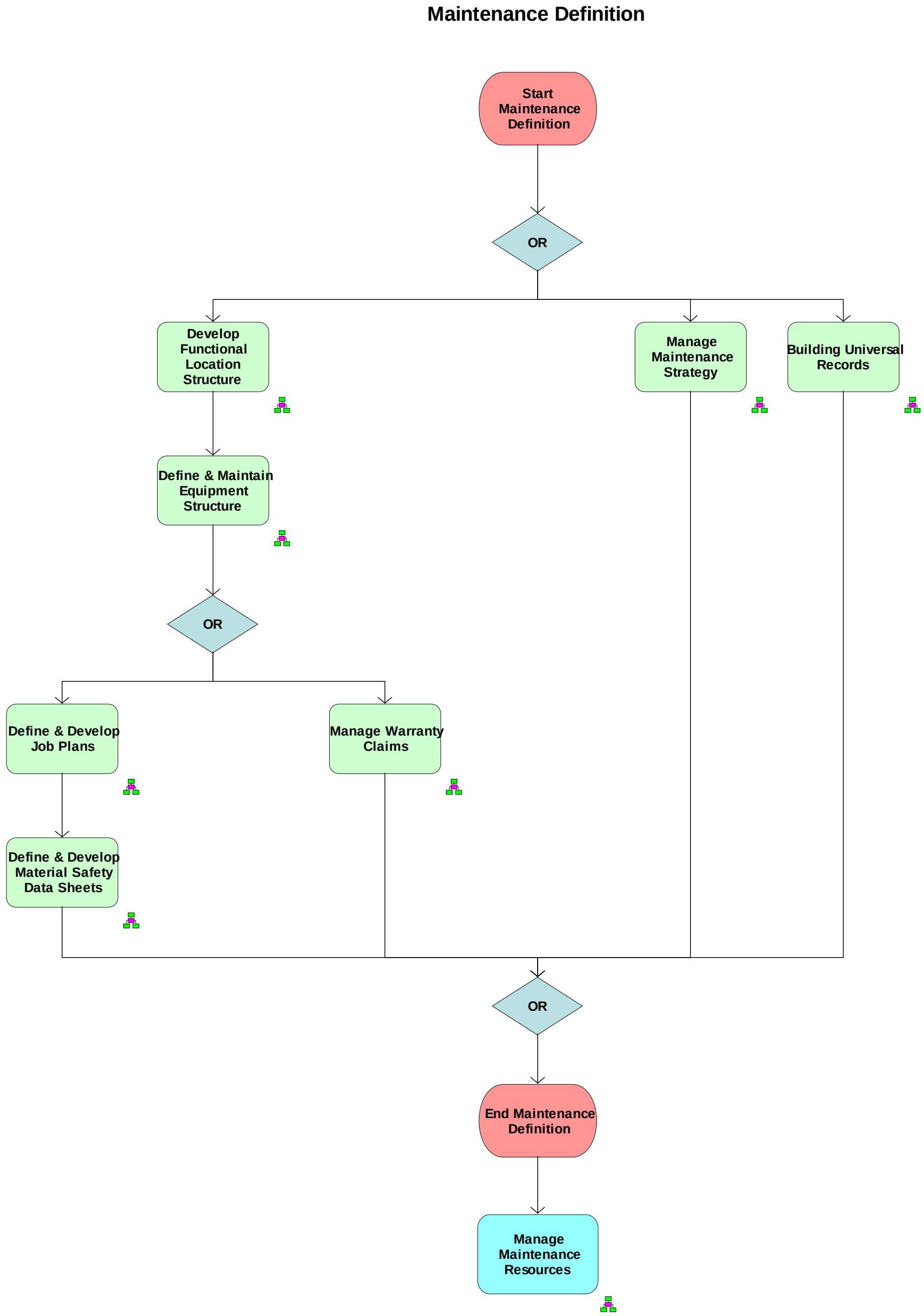


Figure E-2: Manage Maintenance Definition

Model name	Model type	Group
Manage Resources	EPC	Main group\Steam Stations Manufacturing Processes\Level 2

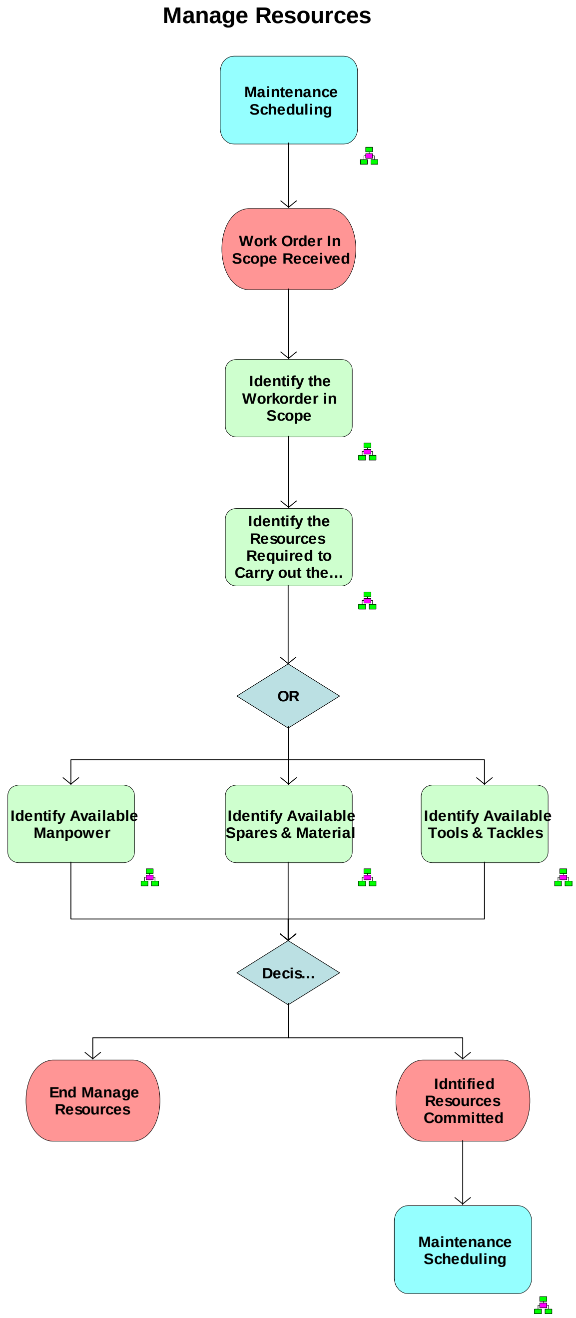


Figure E-3: Manage Maintenance Resources

Model name	Model type	Group
Manage Maintenance Detailed Scheduling	EPC	Main group\Steam Stations Manufacturing Processes\Level 2

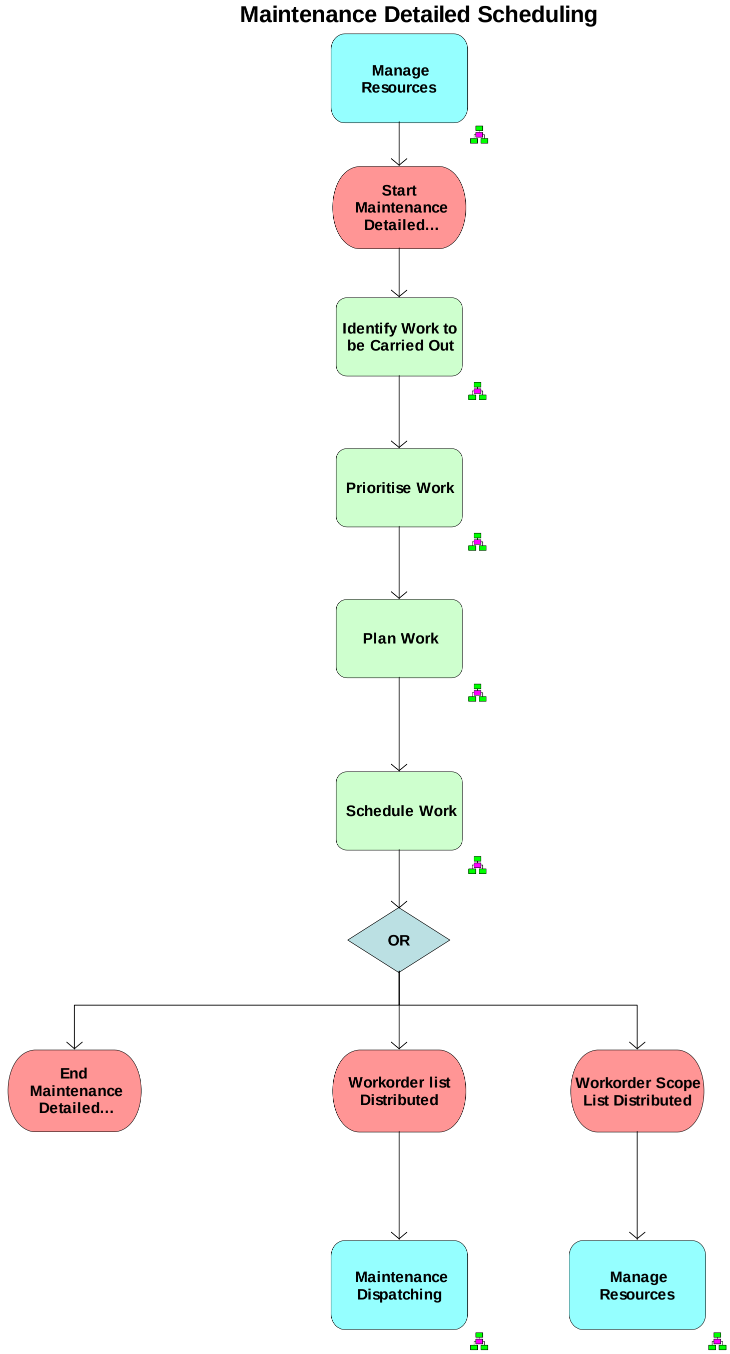


Figure E-4: Manage Maintenance Detailed Scheduling

Model name	Model type	Group
Manage Maintenance Dispatching	EPC	Main group\Steam Stations Manufacturing Processes\Level 2

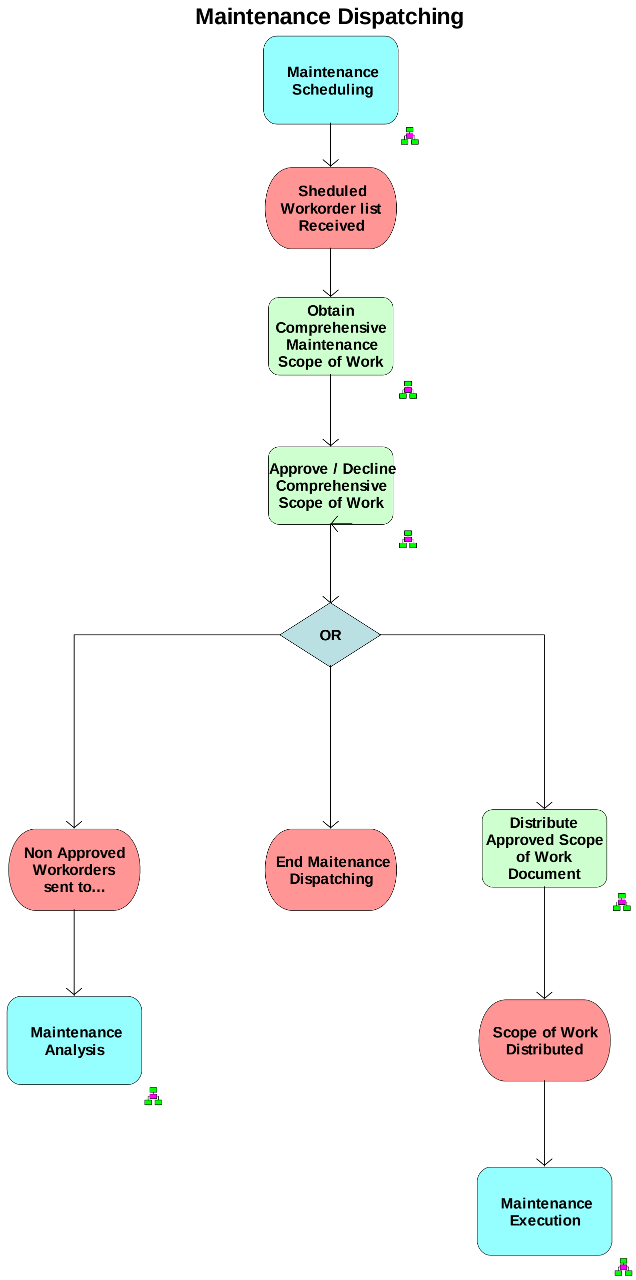


Figure E-5: Manage Maintenance Dispatching

Model name	Model type	Group
Manage Maintenance Execution	EPC	Main group\Steam Stations Manufacturing Processes\Level 2

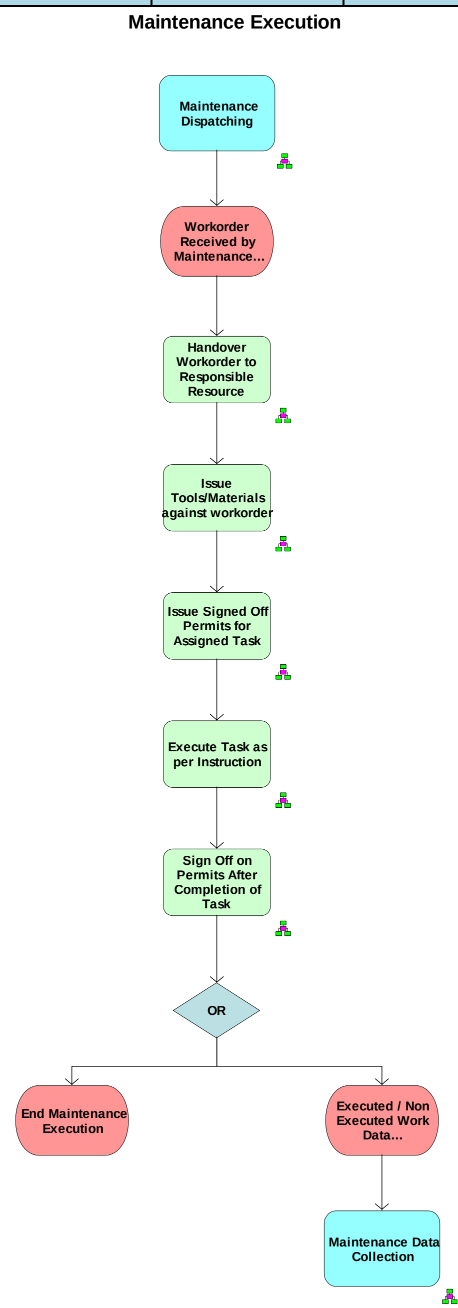


Figure E-6: Manage Maintenance Execution

Model name	Model type	Group
Manage Maintenance Data Collection	EPC	Main group\Steam Stations Manufacturing Processes\Level 2

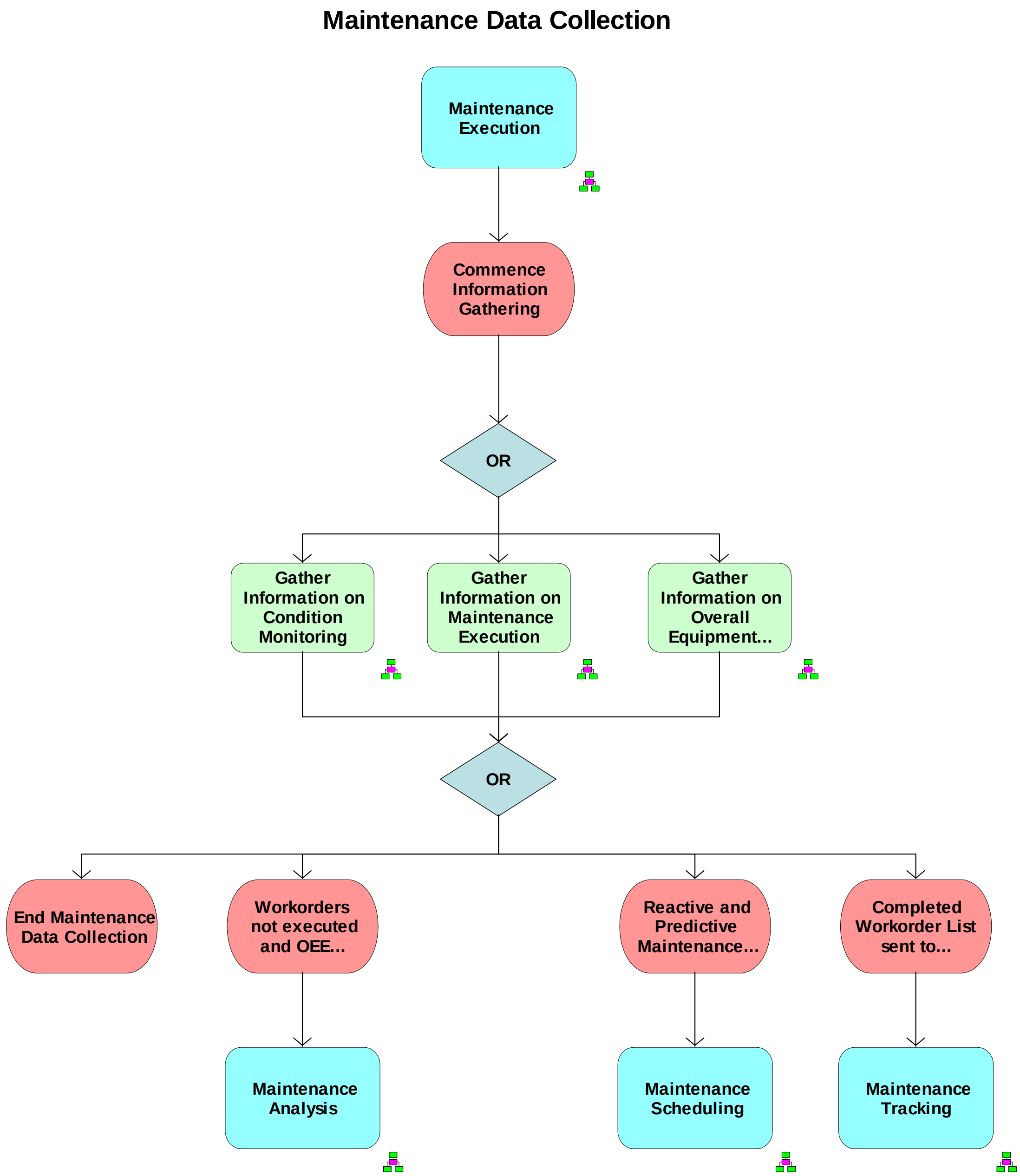


Figure E-7: Manage Maintenance Data Collection

Model name	Model type	Group
Manage Maintenance Tracking	EPC	Main group\Steam Stations Manufacturing Processes\Level 2

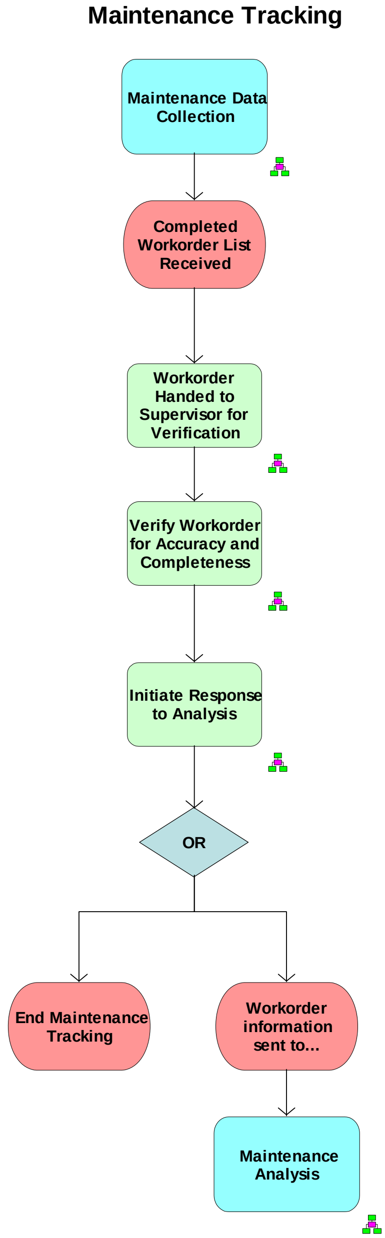


Figure E-8: Manage Maintenance Tracking

Model name	Model type	Group
Manage Maintenance Analysis	EPC	Main group\Steam Stations Manufacturing Processes\Level 2

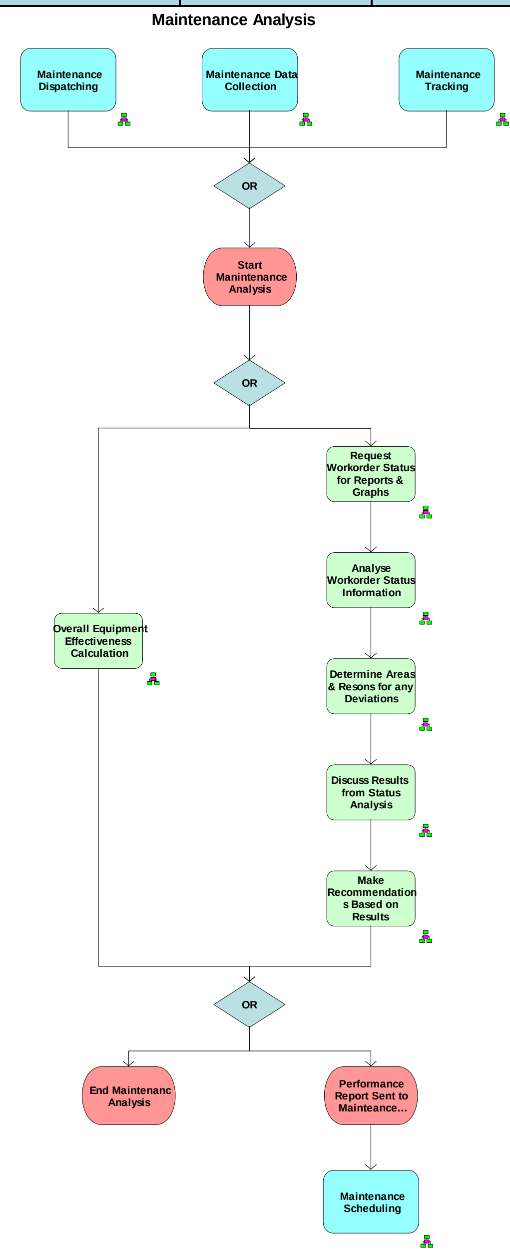


Figure E-9: Manage Maintenance Analysis

F. MANAGE STEAM STATIONS QUALITY

The following sections describes the functional reference architecture specifically the quality process models. The figure below shows the Level 1 business process models. Each process model is composed of lean Event-Drive Process Chain (EPC) diagrams and Functional Allocation Diagrams (FAD's).

Model name	Model type	Group
Manage Quality	Value-added chain diagram	Main group\Steam Stations Manufacturing Processes\Level 1

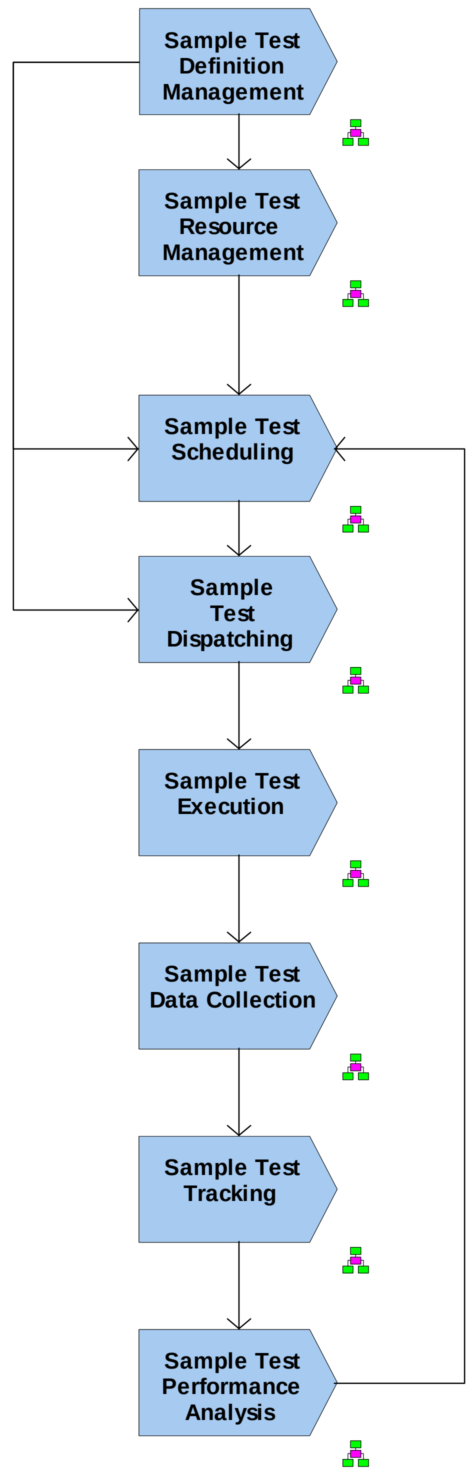


Figure F-1: Manage Steam Stations Quality

Model name	Model type	Group
Sample Test Definition Management	EPC	Main group\Steam Stations Manufacturing Processes\Level 2

SampleTest Definition Management

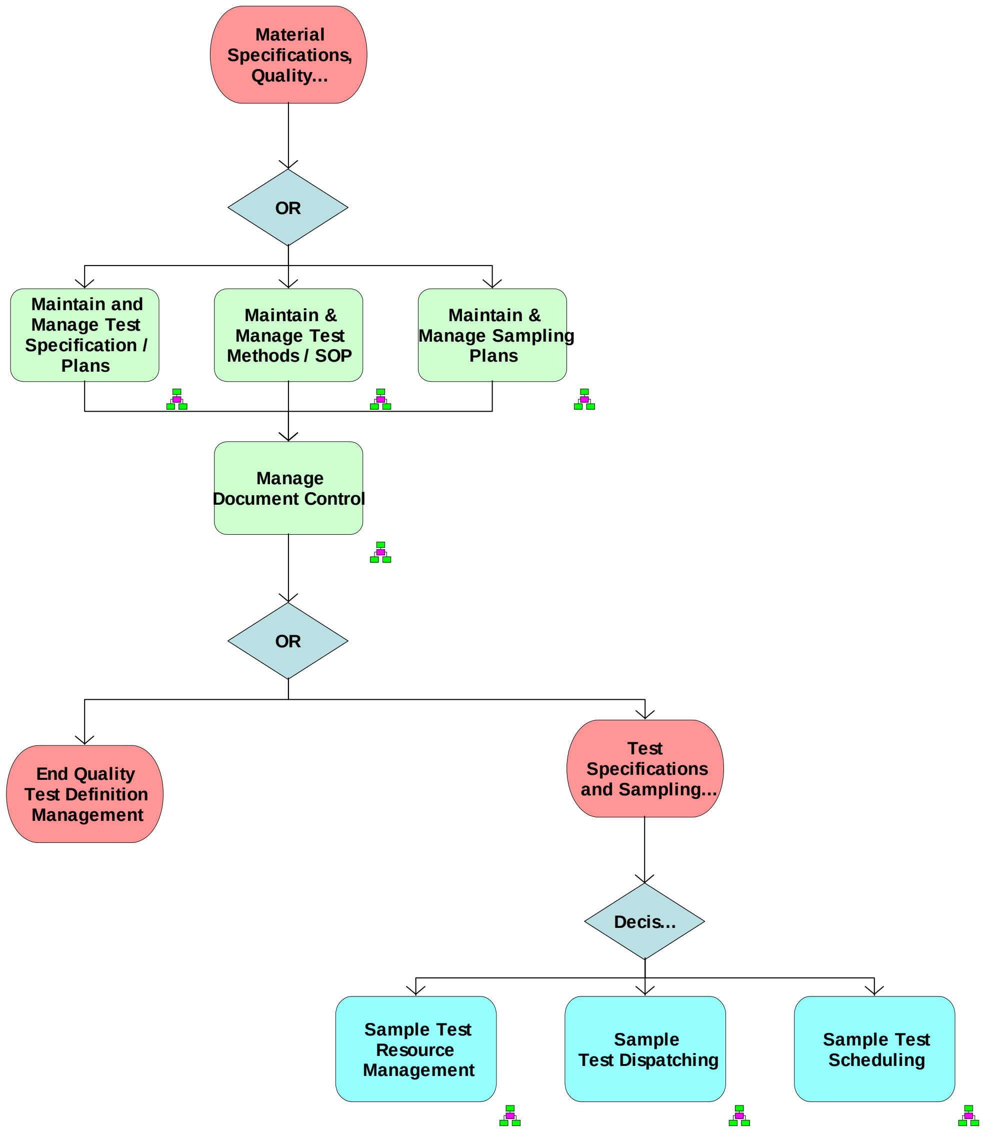


Figure F-2: Sample Test Definition Management

Model name	Model type	Group
Sample Test Resource Management	EPC	Main group\Steam Stations Manufacturing Processes\Level 2

Sample Test Resource Management

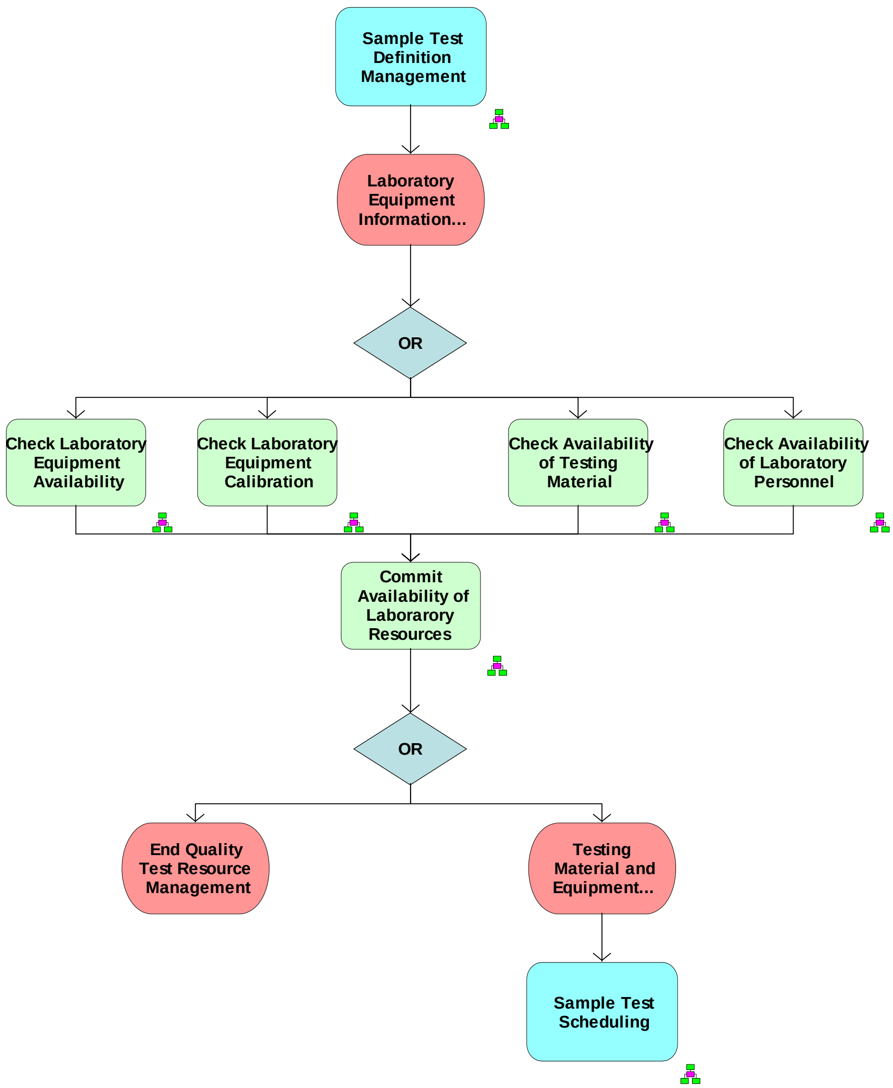


Figure F-3: Sample Test Resource Management

Model name	Model type	Group
Sample Test Scheduling	EPC	Main group\Steam Stations Manufacturing Processes\Level 2

SampleTest Scheduling

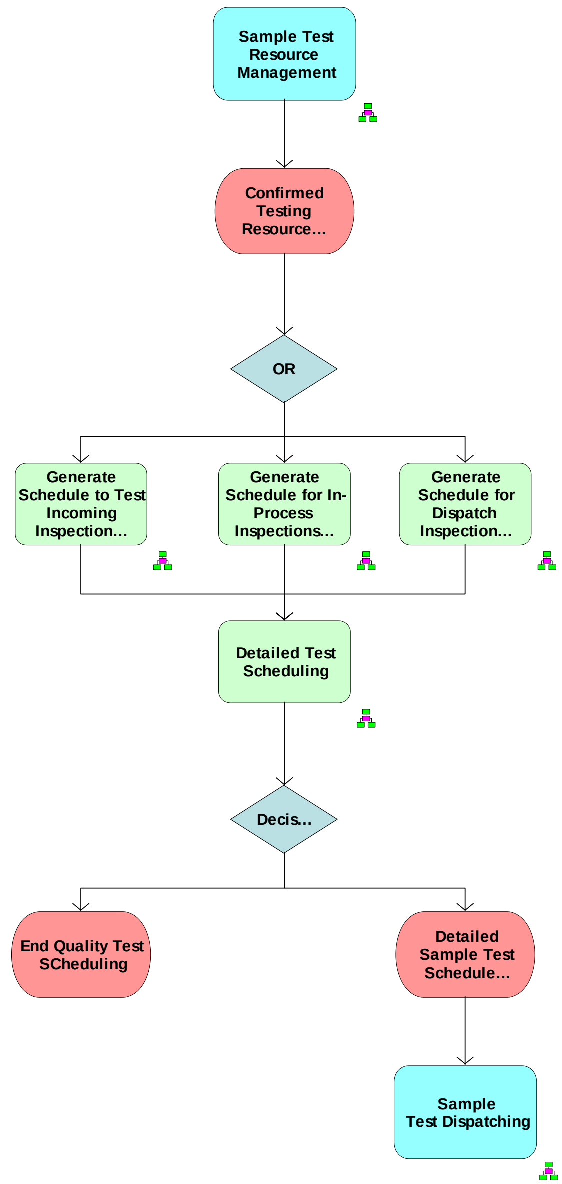


Figure F-4: Sample Test Scheduling

Model name	Model type	Group
Sample Test Dispatching	EPC	Main group\Steam Stations Manufacturing Processes\Level 2

Sample Test Dispatching

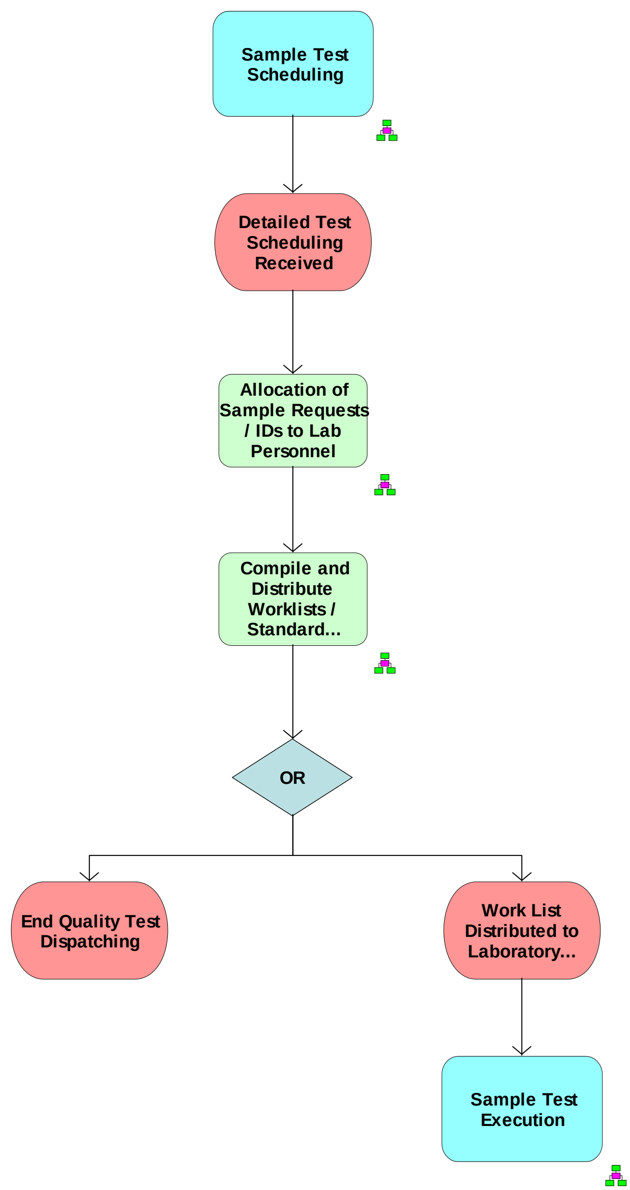


Figure F-5: Sample Test Dispatching

Model name	Model type	Group
Sample Test Execution	EPC	Main group\Steam Stations Manufacturing Processes\Level 2

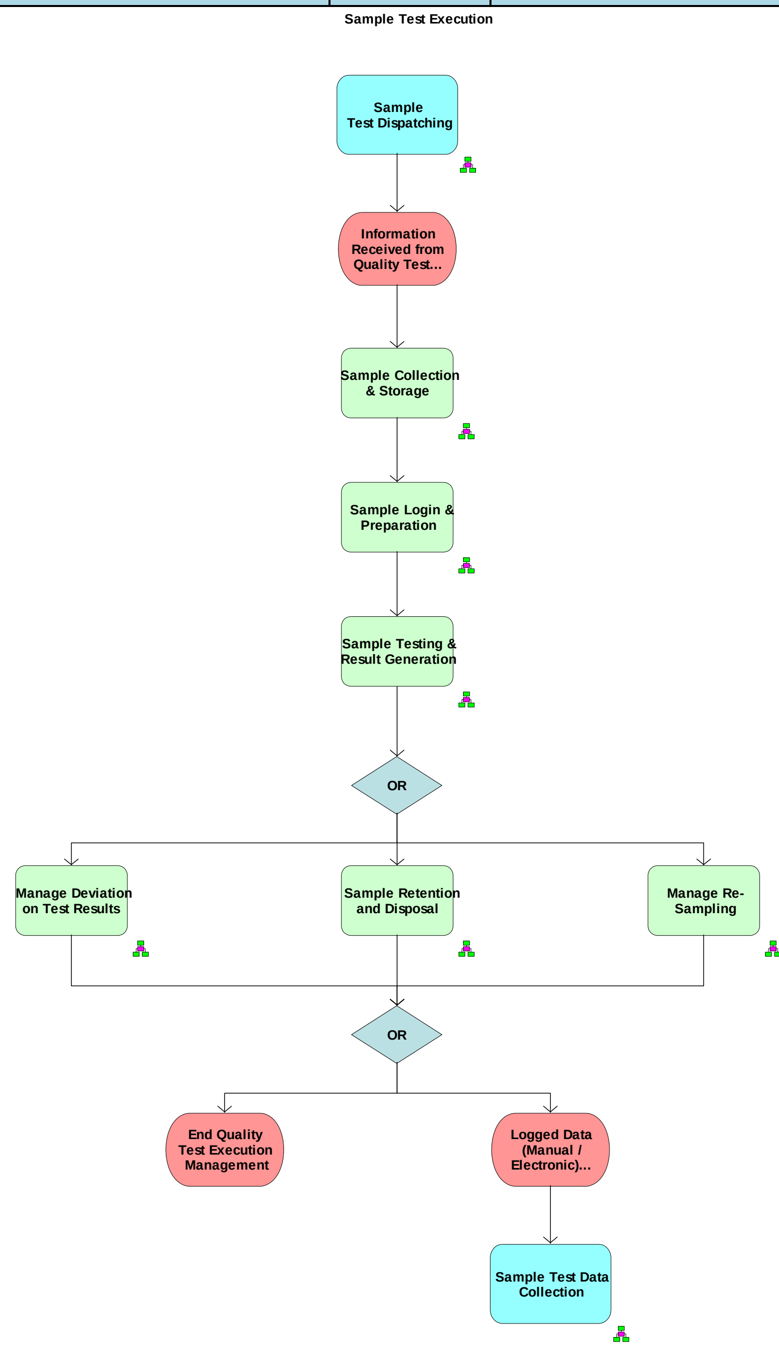


Figure F-6: Sample Test Execution

Model name	Model type	Group
Sample Test Data Collection	EPC	Main group\Steam Stations Manufacturing Processes\Level 2

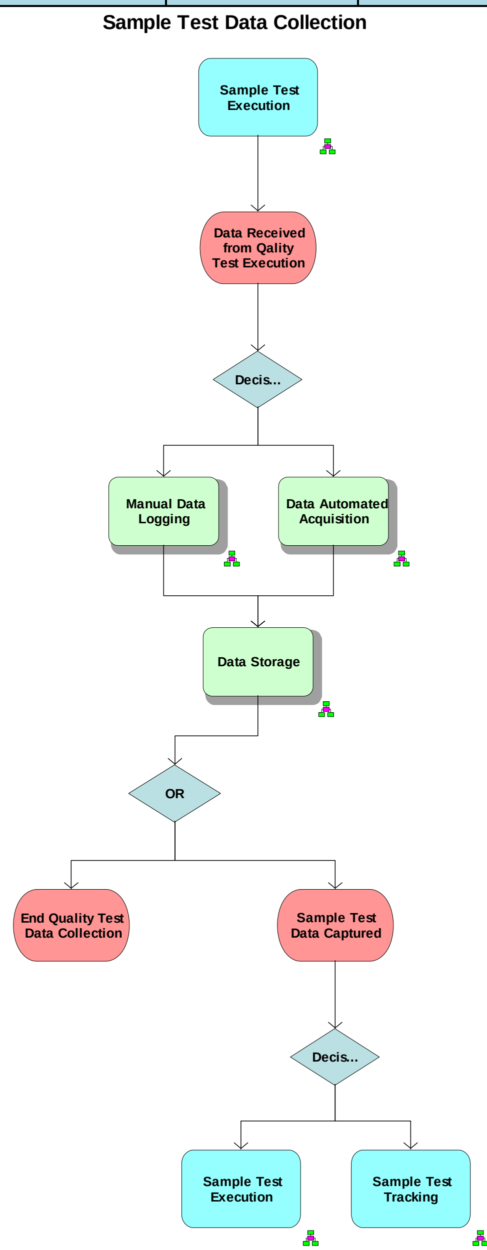


Figure F-7: Sample Test Data Collection

Model name	Model type	Group
Sample Test Tracking	EPC	Main group\Steam Stations Manufacturing Processes\Level 2

Sample Test Tracking

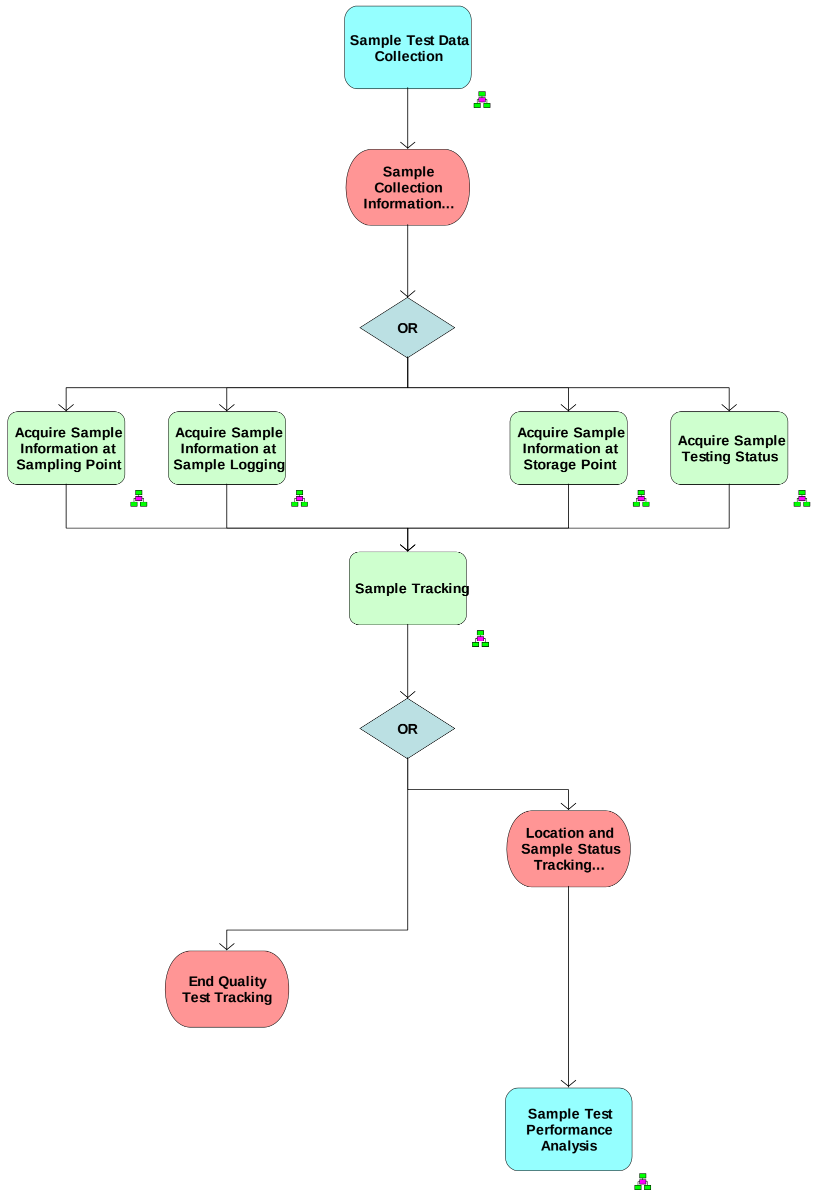


Figure F-8: Sample Test Tracking

Model name	Model type	Group
Sample Test Performance Analysis	EPC	Main group\Steam Stations Manufacturing Processes\Level 2

Sample Performance Analysis

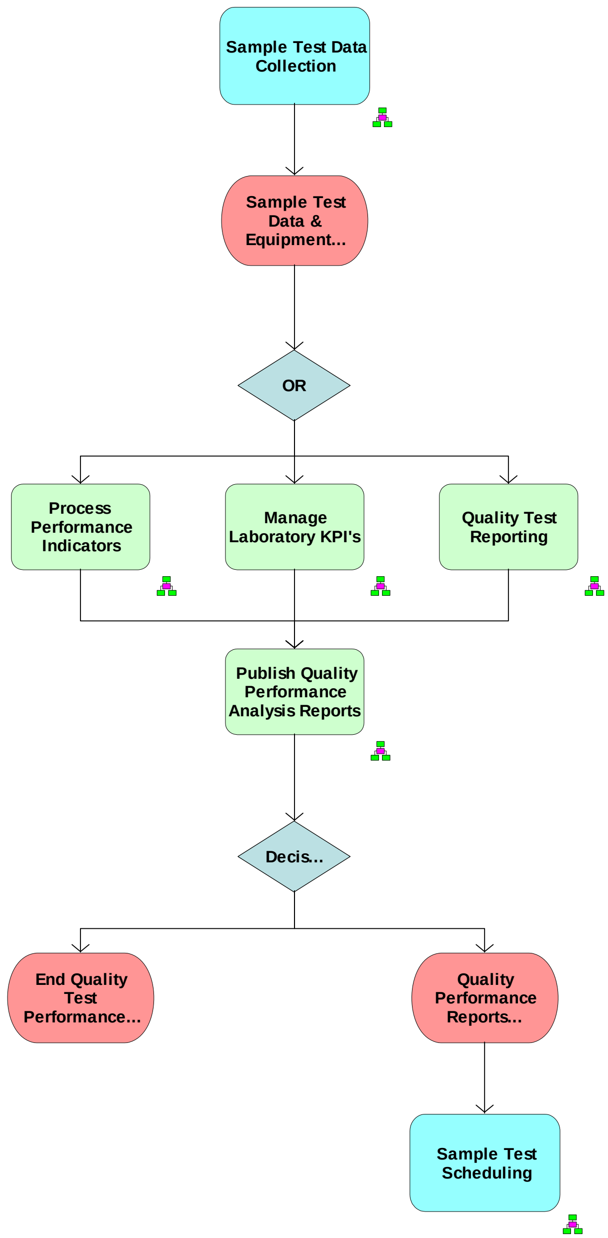


Figure F-9: Sample Test Performance Analysis

G. IT ARCHITECTURE CONSIDERATIONS

1. IT Architecture Considerations

Table G-1: IT architecture considerations

#	Considerations	Score
Connectivity	Systems must be connected to the Sasol network for visibility to other applications.	10
	A security mechanism must be put in place to ensure that data is protected and that access to role based.	10
Manufacturing applications	The application must interface using standard interfaces such as web services.	10
	The application must have a licence and maintenance agreement. This includes all associated hardware.	10
Information Environment	Applications must be hosted on secure managed environments.	10
	Databases must be hosted on secure managed environments.	10
	The application requires business continuity plan in case of failover.	10
Computing environment	The software must be upgraded on a yearly basis to ensure compatibility with other systems and importantly with base system install.	10
Networking environment	The application must store data centrally.	10
	All network hardware must be reliable otherwise fixed or refreshed.	10
Total		100

2. Conceptual MES Architecture – Steam Stations

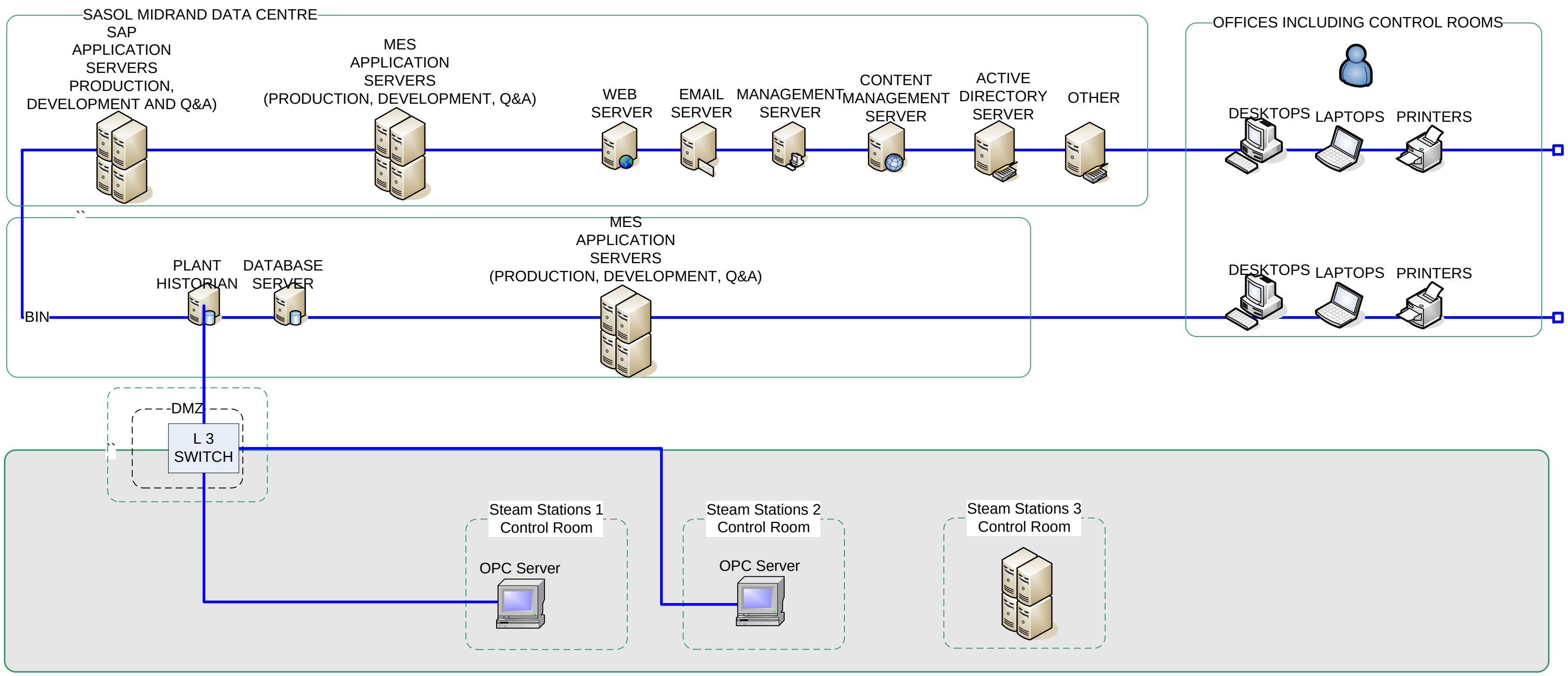


Figure G-1: Steam Stations IT Architecture

3. MES Automation Opportunity

Table G-2: Steam Stations Technology Landscape

#	Application Functionality	Current Technology	Available Technology
1	Document Management System	Livelink	Livelink, Sharepoint
2	Production Planning and Scheduling System	Microsoft Excel populated with information from various sources such as plant historian and thereafter the data is uploaded into SAP with flat files.	Aspen PIMS, Aspen MIMI
3	Logistics Information System	SAP MM for all three Steam Stations	One Mobile, SAP WM, SAP MM, Siemens PLC
4	Tank and Silo Management System	Process Control System or Aspen IP.21	SAP Portal , SharePoint services , Aspen Process Explorer, OSI Pi PHD tools, Pi Process Book;, VB Tools, Excel add-ins (Pi Data Link), Honeywell Uniformance Desktop, Wonderware Active Factory, Crystal reports, Honeywell KPI manager, SAP MII
5	Personnel Availability and Shift Management	Microsoft Excel for Standby Roster Management	SAP HR, Sharepoint

#	Application Functionality	Current Technology	Available Technology
6	Operations Portal	None	SAP Portal, Sharepoint
7	Production Log Management	Microsoft Excel Spreadsheet for log sheets.	SAP MII, SAP Portal, Custom Technologies
8	Process Control Systems	Delta V	Delta V, Siemens
9	Operations Dashboard and Production Event Management	For events the Operations Dashboard at Steam Stations 1 and Steam Stations 2 serves as advisory system to process controllers and managers. Steam Station 3 does not have a system	Aspen DMC Plus, Honeywell RMPCT, PAS Plant State Suite, Aspen PIMS, Honeywell CRO, and Honeywell Operations Manager.
10	Plant Information Management System	Aspen IP.21 is being used to store plant data. Steam Station 1 and 2 are enabled Steam Station 3 does not have a system.	Aspen IP21, OSI Soft Pi, Honeywell PHD, Wonderware InSQL, Citect, SAP MII, Intellitrack.
11	Material Reconciliation	Microsoft Excel with interface to historian for data upload.	Honeywell Blend manager, Aspen PIMS, Honeywell IPS, Blend 2000
12	Plant Performance Management System	Production Dashboards and Reports. These are technology based on .Net environment and Aspen Tech Web.21 technologies. The plant historian and SAP systems are used as input data. Steam Station 1	SAP Portal , SharePoint services , Aspen Process Explorer, OSI Pi PHD tools, Pi Process Book;, VB Tools, Excel add-ins (Pi Data Link), Honeywell Uniformness Desktop, Wonderware Active Factory, Crystal

#	Application Functionality	Current Technology	Available Technology
		and 2 are enabled Steam Station 3 does not have a system.	reports, Honeywell KPI manager, SAP MII
13	Maintenance Strategy System	None	Meridium
14	Maintenance Execution	SAP PM	SAP PM
15	Maintenance Inspections	None	OneMobile, Inspection One , Meridium and SAP Plant Maintenance (PM)
16	Maintenance Equipment health monitoring online system	None	Delta V
17	Work Permit System	None	NiSoft
18	Maintenance Reporting	SAP PM	SAP MI, SAP PM, Meridium, Inspection One
19	Laboratory Information Management System	Infrachem LAB is enabling the core LIMS for the Sasolburg, the Steam stations may interface to the central lab for Certificate of Analysis ad for Sample reports. Currently all steam stations have access to shared service.	LabWare, Sample Manager

Table G-3: MES automation opportunity

Functionality	Current Technology	Available Technology	System Maturity Rating	Score	Maximum
Production Planning and Scheduling System	Microsoft Excel with flat file interface to SAP.	Aspen PIMS, Aspen MIMI	Stand Alone System	2	5
Production Reconciliation	Microsoft Excel with interface to historian for data upload.	Honeywell Blend manager, Aspen PIMS, Honeywell IPS, Blend 2000	Stand Alone System	2	5
Production Event Management	Current Production Dashboard at Steam Stations 1 and Steam Stations 2 serves as advisory system to operators and managers. Steam Station 3 does not have a system	SAP PP, Aspen DMC Plus, Honeywell RMPCT, PAS Plant State Suite, Aspen PIMS, Honeywell CRO, and Honeywell Operations Manager.	Stand Alone System suitably managed	3	5
Plant Performance Management System	Production Dashboards and Reports. Custom Technology based on .Net environment and using plant historian for data.	SAP Portal , SharePoint services , Aspen Process Explorer, OSI Pi PHD tools, Pi Process Book;, VB Tools, Excel add-ins (Pi	Stand Alone System suitably managed	3	5

Functionality	Current Technology	Available Technology	System Maturity Rating	Score	Maximum
	Steam Station 1 and 2 are enabled Steam Station 3 does not have a system.	Data Link), Honeywell Uniformance Desktop, Wonderware Active Factory, Crystal reports, Honeywell KPI manager, SAP MII			
Plant Information Management System	Aspen IP.21 is being used to store plant data. Steam Station 1 and 2 are enabled Steam Station 3 does not have a system.	Aspen IP21, OSI Soft Pi, Honeywell PHD, Wonderware InSQL, Citect, SAP MII, Intellitrack.	Stand Alone System suitably managed	3	5
Electronic Logsheets	Microsoft Excel	Aspen, Honeywell, SAP	Stand Alone System	2	5
Logistics Information System	SAP MM for all three Steam Stations	One Mobile, SAP WM, SAP MM, Siemens PLC	Stand Alone System	2	5
Laboratory Information Management System	Infrachem LAB is enabling the core LIMS for the Sasolburg, the Steam stations may interface to	LabWare, Sample Manager	Stand Alone System suitably managed	3	5

Functionality	Current Technology	Available Technology	System Maturity Rating	Score	Maximum
	the central lab for Certificate of Analysis ad for Sample reports. Currently all steam stations have access to shared service.				
Deviation Management System	Current captured and reported in the RCAT incident management system	Meridium, RCAT, SAP QM	Stand Alone System	2	5
Maintenance Strategy	Microsoft Excel	Meridium	Stand Alone System	2	5
Equipment Inspection	Microsoft Excel	OneMobile, Inspection One , Meridium and SAP Plant Maintenance (PM)	Stand Alone System	2	5
Maintenance Execution	SAP PM	SAP PM	Stand Alone System suitably managed	3	5
				29	60

Table G-4: Legend: System Rating or Score

System	Rating/Score
Functionality not required	0
Manual	1
Stand Alone System	2
Stand Alone System suitably managed	3
Integrated systems	4
Integrated systems both suitably managed	5

CD – ROM CONTENT

H. FUNCTIONAL REQUIREMENTS QUESTIONAIRE AND TOOLSETS (CD – ROM)

1. Description

This appendix describes the approach and requirements gathering toolsets to capture functional requirements from the steam stations personnel. An analysis was done to compare the business process activities and application functionality. Also included, are examples of toolsets with functional requirements captured.

2. File Format

- Adobe Acrobat Document

I. MANAGE STEAM STATIONS PRODUCTION AND INVENTORY FUNCTIONAL REQUIREMENTS (CD – ROM)

1. Description

This appendix describes the Steam Stations Production and Inventory Operations functional requirements specifically for Steam Station 1, Steam Station 2 and Steam Station 3.

2. File Format

- Adobe Acrobat Document

J. MANAGE STEAM STATIONS MAINTENANCE FUNCTIONAL REQUIREMENTS (CD-ROM)

1. Description

This appendix describes the Steam Stations Maintenance functional requirements captured from the Steam Stations specifically Steam Station 1, Steam Station 2 and Steam Station 3

2. File Format

- Adobe Acrobat Document

K. MANAGE STEAM STATIONS QUALITY FUNCTIONAL REQUIREMENTS (CD-ROM)

1. Description

This appendix describes the Steam Stations Quality functional requirements captured from the Steam Stations specifically Steam Station 1, Steam Station 2 and Steam Station 3

2. File Format

- Adobe Acrobat Document

L. MES SYSTEM OPTIMISATION (CD-ROM)

1. Description

Appendix J, appendix K and Appendix L classified the functional requirements according to criticality. This appendix describes the conceptual design to enable these requirements and optimise the current MES currently installed.

2. File Format

- Adobe Acrobat Document