EVALUATING BENEFITS REALISATION MANAGEMENT (BRM) METHODOLOGY AS A TOOL FOR IMPLEMENTING MANUFACTURING EXECUTION SYSTEMS (MES)

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

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DECLARATION

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

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ABSTRACT

This research report addresses the question: Is BRM (Benefits Realisation Management) a valid method for MES (Manufacturing Execution Systems) development and implementation?

While the technical aspect of implementing MES is standardised and well documented, a clear approach to tackling the activity on a company specific level is missing. Literature shows that there is ambiguity in where ownership should lie and further details common organisational problems that companies experience. Limited guidance is given to how these problems can be tackled.

An evaluative case study is conducted at the WMMEA (WEIR Minerals Middle East and Africa) machine shop to determine whether BRM methodology is able to improve the MES system and its implementation by adding a previously unexplored structure to the undertaking. The research method focuses on two aspects of the case. The initiative, where the researcher aims to identify whether BRM methodology is able to specify a complete set of requirements for MES implementation. The outcomes, where the researcher quantifies the benefits gained from the implementation.

This report describes an adapted BRM methodology and the outcomes of its application. These outcomes consist of the issues faced by the company, the enablers developed to overcome these issues, and the benefits derived from MES.

The BRM methodology is shown to be valid in the case of WMMEA by the confirmed realisation of predicted benefits. The business objectives achieved are an improved on-time delivery to customers and an increased part value.

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NOMENCLATURE

B2MML – Business to Manufacturing Markup Language
BPR – Business Process Re-engineering
BRM – Benefits Realisation Management
CIM – Computer Integrated Manufacturing
DIMS – Dynamically Integrated Manufacturing System
ERP – Enterprise Resource Planning
GAMP – Good Automated Manufacturing Practice
GUI – Graphical User Interface
HTML – HyperText Markup Language
IoT – Internet of Things
ISA – International Society of Automation
IT – Information Technology
JSE – Johannesburg Stock Exchange
KPI – Key Performance Indicator
MES – Manufacturing Execution Systems
MESA – Manufacturing Enterprise Solutions Association
MRP – Material Requirements Planning
MRPII – Manufacturing Resource Planning
MTO – Make to Order
MTS – Make To Stock
OEE – Overall Equipment Effectiveness
OTD – On Time Delivery
RCA – Root Cause Analysis
ROI – Return on Investment
S&OP – Sales and Operations Planning
SMS – Short Message Service
SQL – Structured Query Language
WIP – Work in Progress
WMMEA – Weir Minerals Middle East and Africa (Company)
XML – eXtensible Markup Language
ZAR – South African Rand

1. INTRODUCTION

1.1. Background

Manufacturing methods and processes evolve as materials, technology, and customer needs develop. Bi et al. [1] state that computing technology in particular has led to mass redevelopment of numerous manufacturing and general enterprise functions.

The idea of integrated production systems began to pick up in the late 1970s. Attaran [2] highlights early success case studies from well-known technology companies such as Motorola, Allen Bradley, and Texas Instruments. His discussion however focuses on the high rate of implementation failure and the technical and organisational reasons behind these failures. The term Manufacturing Execution Systems (MES) emerged in the early 1990s. The book by Meyer et al. [3] gives an overview of all aspects of modern MES systems. They frame these as <u>production oriented Information Technology (IT) systems used to support, in real time, processes in complex or dynamic environments</u>. They also explain the various integration standards and technologies that have, since Attaran's report (1997), emerged to overcome the technical integration issues. Many of the organisational issues plaguing MES implementations are however still present.

This report investigates whether Benefits Realisation Management (BRM) is a valid methodology for MES development and implementation. BRM (as defined by Bradley [4]) is a method used for specifying and monitoring change initiatives (or projects). It is based on ensuring the required benefits are derived from these initiatives. BRM usually focuses on higher-level company objectives and draws a causal link between these and the lower-level initiatives taking place in the company. While BRM is applicable in the broad field of programme management, its chief application has been in IT projects. Doherty et al. [5, p8] explain this applicability saying: "*Technologically-mediated organisational changes* (such as MES) *come in all shapes and sizes. For example, an* *organisation is far more likely to realise benefits from its new* (Enterprise Resource Planning) *ERP implementation if it explicitly redesigns its working practices to more closely reflect the process model embedded in the system"*.

The keystone of this evaluation is an MES implementation case study at the Weir Minerals Middle East and Africa (WMMEA) machine shop.

1.2. Research Question

This research report addresses the question: *Is BRM a valid method for MES development and implementation?*

The report addresses the question through a case study at WMMEA and lays the groundwork towards answering the question on a generalised scale. The results of this research could in turn contribute to the development of a best practise methodology for MES implementation, recognizing that a single case study is insufficient to generalize for all MES implementations. The following sections of this chapter aim to put the question into context by defining the case, its boundaries, and the propositions posed.

1.3. Case Background and Context

This case study is based on an MES realignment project done in the WMMEA machine shop.

WMMEA produces and maintains equipment used in the mining mill-circuit. Major components of this circuit are slurry and dewatering pumps. WMMEA manufactures key components for these pumps. The WMMEA machine shop falls into the small lot and Make-To-Order (MTO) category of manufacturing:

- Average part weight = 141kg (Sample deviation = 214).
- Average part cost = ZAR 7’306 (Sample deviation = 10’898).
- Average batch size = 5.6 units (Sample deviation = 9.4).

[Order book snapshot for September 2014].

The machine shop where this takes place already had an MES system installed but this system was perceived as not working optimally. An MES realignment project was undertaken to identify the shortfalls of the system and then bring it into line with the company’s business objectives. This report avoids going into what went wrong in the initial implementation and focuses only on the realignment initiative.

WMMEA manages its data and operations through a BAAN ERP system from Infor. The underlying relational database management system is from the Oracle Corporation. Integration with the MES system is achieved through data staging tables. This method uses a query language to populate an intermediate “staging” table with data that needs to be processed into MES or into the ERP (also known as the remote procedure invocation model to be described further in the *“Literature Review”* chapter). The MES system features a HyperText Markup Language (HTML) based Graphical User Interface (GUI) and the database is based on Microsoft’s Structured Query Language (SQL) server software.

As noted earlier, BRM was selected as the preferred methodology for implementing MES at WMMEA. While BRM has been generalised for software implementation, it has never (based on the available literature) been applied to the specific context of MES. WMMEA was willing to consider BRM as an approach, warranted by the complex integration specification required by MES systems.

Root Cause Analysis (RCA) was used extensively for identifying the reasons for the initial unsatisfactory implementation. RCA will however not be covered extensively in this report as it is not inherently a precursor to BRM initiatives.

1.4. Propositions

Two propositions are presented. In order to answer the research question, both have to be shown to be true.

1. *It is possible to apply an adapted BRM methodology to specify the requirements of MES systems for the WMMEA machine shop.*

   This proposition focuses on the initiative. It requires the report to track the implementation from start to finish giving the reader insight into the real event that took place over time, the people who were involved, and the way tasks were handled. Most importantly, it evaluates whether the company was able to apply the methodology and whether the methodology was adhered to. The adaptation and reason for adaptation is detailed in the *"Theoretical Framework"* chapter that follows.

   In order to determine if the methodology has been applied correctly, the following must be met:

   - All of the steps specified by the methodology have been taken.
   - In the requirement specification, there is a causal link chain between all enablers and WMMEA's company objectives.
   - Stakeholders work to execute the requirements at WMMEA, until the system reaches a new baseline level. The details of the requirements execution are out of the scope of this report.

2. *The benefits predicted by the BRM methodology have been realised.*

   This proposition focuses on the outcomes. There is both a quantitative and qualitative aspect to this proposition.
   The quantitative perspective is a measurement of the extent to which the benefits of MES at WMMEA have been realised. The report is required to show that the change in the predicted benefits is in the desired (and predicted) direction.
   The following points need to be taken into account:

- All benefit measurements are defined and put in place.
- The frequency of measurements is not specified due to the practicality of obtaining the measurements. More data points are preferred but at least two are essential to show a trend.
- Note any points in time when a step change in the system is instated or an event that will influence system behaviour occurs.

From a qualitative perspective, the report needs to confirm the validity and reliability of the predicted causal links.

The following points need to be taken into account:

- Summarising the measurements on the benefit tracking template in order to analyse the relationship between benefits over a common time frame. While the main (quantitative) analysis focuses on the trend of individual benefits, identifying potential relationships between benefits gives added assurance that these trends are not coincidental.
- Although there are no benchmarks for the extent to which a benefit should change, this extent should nevertheless be considered for validity purposes.
- The researcher, acting as a participant observer within the company, is to give his opinion on any events or measurements he feels could be misleading to the reader.

1.5. Scope Delimitations

This section presents the boundaries of the case study.

1.5.1. Scope Delimitations of the MES System

The Manufacturing Enterprise Solutions Association (MESA) [6] identifies 11 potential functions of MES systems. The system under consideration at WMMEA however only performs the first four (a short elaboration is given for how each function is handles at WMMEA):

- Resource Allocation and Status – Handled by WMMEA's MES system.
- Process Management – Handled by WMMEA's MES system.
- Performance Analysis – Handled by WMMEA's MES system.
- Data Collection/ Acquisition – Handled by WMMEA's MES system.
- Operations/ Detail Scheduling – Performed by a separate, integrated, package. Queue length is an input from MES.
- Dispatching Production Units – Performed by the ERP.
- Document Control – Performed by the ERP.
- Labour Management – Performed by a separate, standalone, package.
- Quality Management – Performed by a separate, integrated, package.
- Maintenance Management – Performed by a manual system.
- Product Tracking and Genealogy – Not a machine shop requirement.

1.5.2. Scope Delimitations of BRM

This report focuses on the application of an adapted BRM methodology for MES system implementation and the measurement of derived benefits. Generally however, a major aspect of BRM methodology is the Return On Investment (ROI) calculation. ROI is a company specific analysis of the cost associated in implementing the system, weighed out against the benefits. ROI considerations will not be addressed in this report.

1.5.3. Delimitations of the Case Study

The initiative underlying this report is company specific. There was an opportunity to study a single implementation at a single company. The inputs and outcomes to the initiative are limited to only what was needed to satisfy the company objectives; and as a result, considerations that may be valid in other environments are not taken into account.

There is no control or alternative method under consideration. It is therefore not possible to benchmark the relative effectiveness of the methods described in this report against other methodologies.

No benchmark is specified for the benefits to be gained. MES system providers do estimate the benefits their systems will bring. These estimates are usually in the form of high level benefits such as productivity or ROI. The researcher is unable to reliably compare these to the company objectives. Benchmarks for the lower level benefits are unavailable. In addition, Scholten [7] suggests that much of this data could stem from biased sources.

1.6. Uncontrollable Events

Two major uncontrollable events affected the implementation of the MES system under consideration.

- The initiative was launched in November 2013. In March 2014, while the project was underway, the company underwent a major ERP change. This resulted in the majority of the MES system having to be turned off for 3 months until the changes were complete. Furthermore, there is a learning curve to the company familiarising itself with the new ERP. The researcher suggests that this may have had unknown effects on total system performance as far as a year after implementation.
- Strike action in July 2014 lasted 4 weeks during which time the company fell behind on its targets. The MES system was online,

however the company focus had shifted from system implementation to catching back lost production. Dedicated focus on the MES initiative was only resumed at the start of January 2015.

1.7. Report Structure

This report is a case study evaluation. The aim of such a report is two-fold. Firstly, it details the complex initiative and the environment in which it took place. Because the case is not a completely controlled event, it is important that the reader understands the shortfalls and opportunities that lead to the described outcomes. Secondly, it details the results obtained in the initiative and evaluates them using various methods. This is required because there is no single, perfectly defined, mathematical relationship which is able to capture complex social activity.

The structure is as follows:

- Chapter 1 presents a discussion on the research question and its importance. The question is stated formally, the case and its limitations are defined, and propositions are developed against which the question will be evaluated.
- The literature review in Chapter 2 takes the reader through the current state of the art with respect to modern manufacturing, ERP & manufacturing data management, MES systems, and BRM. In doing this, it highlights the integration gap that this research addresses.
- Two theoretical concepts dominate this report. MES systems and BRM methodology. With regard to MES systems, this report focuses mainly on the benefits that they provide. It does not detail their working further than what is necessary for understanding the concept. In order to evaluate the applicability of BRM methodology

however, it has been detailed in Chapter 3. These details dictate each of the steps taken by the company during the initiative.

- Chapter 4 explains case study research methodology for evaluations. The use of appropriate methodology is essential for ensuring the validity and reliability of research findings.
- Chapter 5 details the results. For the first proposition, these are the outcomes of the applied methodology. For the second, these are the benefit measurements.
- Chapter 6 discusses the results with respect to the propositions. It also addresses issues of validity and reliability.
- Chapter 7 concludes the outcomes of the research and answers the research question.
- Finally, Chapter 8 discusses the researcher’s ideas about where this research could lead.

2. LITERATURE REVIEW

This literature review is structured such that it will lead the reader from the current issues affecting the small lot and MTO manufacturing environment; then through the uses and shortfalls of current ERP and database systems employed by companies; and toward the requirements for MES system implementation. The last part of the literature review summarises BRM methodology and explains why it may have potential for use with system implementation such as MES.

2.1. Review of Modern Manufacturing Implications

Increasing complexity is one of the biggest challenges facing manufacturing today. El Maraghy et al. [8] summarise the various sources of complexity in Figure 2-1, showing the four categories that drive complexity:

- External pressures such as standards and legislation
- Market forces
- Product & Hard Enablers
- Process & Soft Enablers

Figure 2-1: Sources of manufacturing complexity [8].

Bullen [9] explains that the small batch plant MTO industry has largely been hit with customer demand for smaller runs and custom-designed products which favours agile and adaptive workplace models. What follows are some methods and best practices being used by companies to meet these sometimes conflicting, interrelated, and very complex requirements.

Zhang et al. [10] show that historical practices are no longer adequate in a rapidly changing manufacturing environment. Alternative system configurations and structures must be considered when the current system is no longer able to meet challenges in the market. Many technologies, operating systems, and paradigms have been developed in response.

A paper by Belisario and Pierreval [11] outlines a framework to characterise systems that aim at quickly or continuously modifying their production facilities to changing environments. The framework is based on the process of adaptation (Figure 2-2) which shows how the adaptation of companies has a knock-on effect on its competition, environment, and customer behaviour.

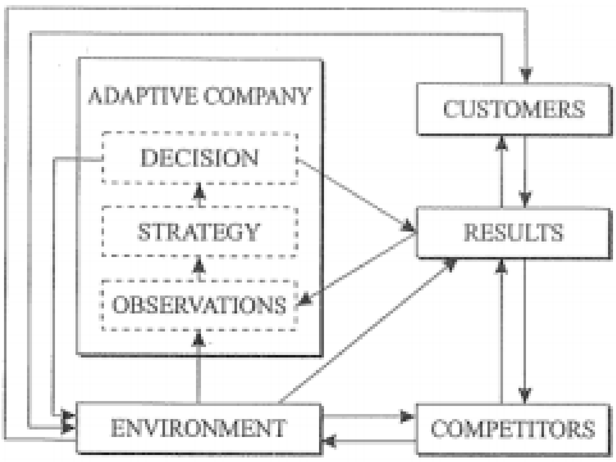


Figure 2-2: Process of adaptation [11].

Their framework proposes a function consisting of seven parameters:

1. Change object(s).
2. Type(s) of change.
3. Information used.
4. Triggering strategy.
5. Organisational structure.
6. Changing mechanism.
7. Objectives.

Bullen [9] mentions the following as enablers to achieving this state of adaptability: Integrated Product Process Design; and Advanced Analytics such as Multi-Disciplinary Design Analysis Optimization, Actionable Intelligence, Factory Command and Control, and Expert Systems. An example of a truly responsive system is a Dynamically Integrated Manufacturing System (DIMS) as described by Zhang et al. [10]. Their DIMS model allows tasks to be planned to satisfy delivery time at optimised cost; and alternative system configurations and structures to be considered when market conditions change. Al-Aomar [12] suggests that due to the increasing complexity of operations, new techniques (such as discrete event simulation) for creating and managing performance metrics are required. All of these methodologies, paradigms, etc. add levels of complex computer-based systems.

2.2. Review of Modern ERP and Database Structures

As companies get larger and increase in complexity, the number of transactions and quantity of data they must process and store increases beyond the management and communication ability of single-client software. ERP software is generally a suite of tools used by businesses to manage and "make sense" of the large amounts of data they generate. Maedche [13] explains that one major goal of ERP systems is to integrate all the relevant master and transactional data of the enterprise and let people and processes operate on the same data.

Rashid et al. [14] detail the evolution of ERP systems saying they began in the form of Material Requirements planning (MRP) and Manufacturing Resource Planning (MRPII); that they were traditionally developed for manufacturers; and that they were primarily for inventory and manufacturing management. Hawking et al. [15] discuss the primary benefits a modern packaged ERP business solution is expected to deliver.

These are:

1. Improved management decision making.
2. Improved financial management.
3. Improved customer service and retention.
4. Ease of expansion and increased flexibility.
5. Faster, more accurate, transactions.
6. Headcount reduction.
7. Cycle time reduction.
8. Improved inventory and asset management.
9. Fewer physical resources and better logistics.
10. Increased revenue.

They note that these benefits are however often not achieved in the initial implementation due to lack of skill and experience with the new systems (49% of companies considered ERP implementation as a continuous process). Meyer et al. [3] however say that many of these goals are over ambitious for MRP which has settled in as being software for automating accounting and administrative systems.

In the previous section on modern manufacturing, it is noted that to remain competitive, firms must be agile and responsive. This is however often in conflict with ERP systems, which have evolved to have rigid structures (to promote reliability) and which may not lend themselves well to the modern manufacturing requirements. Bi et al. [1] identify the ultimate shortcomings of modern enterprise systems noting that they are incapable of dealing with change or uncertainty, have software and hardware that is not suited to flexibility, do not allow for virtual collaboration, and are not designed for sustainability. They suggest that the emerging Internet of Things (IoT) infrastructure can support information systems of next generation enterprises more effectively.

So far, the discussion on ERP has identified its purpose and also its limitations. Beach et al. [16] explain that many suppliers of ERP software now develop their systems around third-party industry standard database engines. This enables enterprises to use common high-level query languages like Microsoft SQL and Oracle SQL to develop or integrate operational specific applications such as MES. The International Society of Automation (ISA) [17] has compiled the ISA95 standard for Enterprise

Control System Integration. This standard defines a functional system hierarchy (Figure 2-3) and the boundaries between each level in the hierarchy. Typically, ERP systems would reside on level 4 while MES systems would reside on level 3. A company that adheres to this standard would therefore handle the functions that reside on level 4 using its ERP and those that reside on level 3 using its MES. Purchasing an ISA95 compliant MES would not pose an integration issue to an ISA95 compliant company, because all date inputs and outputs at the boundaries of the systems match. It is however common to see companies deviating from this standard (WMMEA is an example). There are many reasons. The company, in its early days, may not have foreseen a need for adherence to it; the company's systems may predate the standard; or the company may have had to customise its structure to accommodate other un-adhering systems.

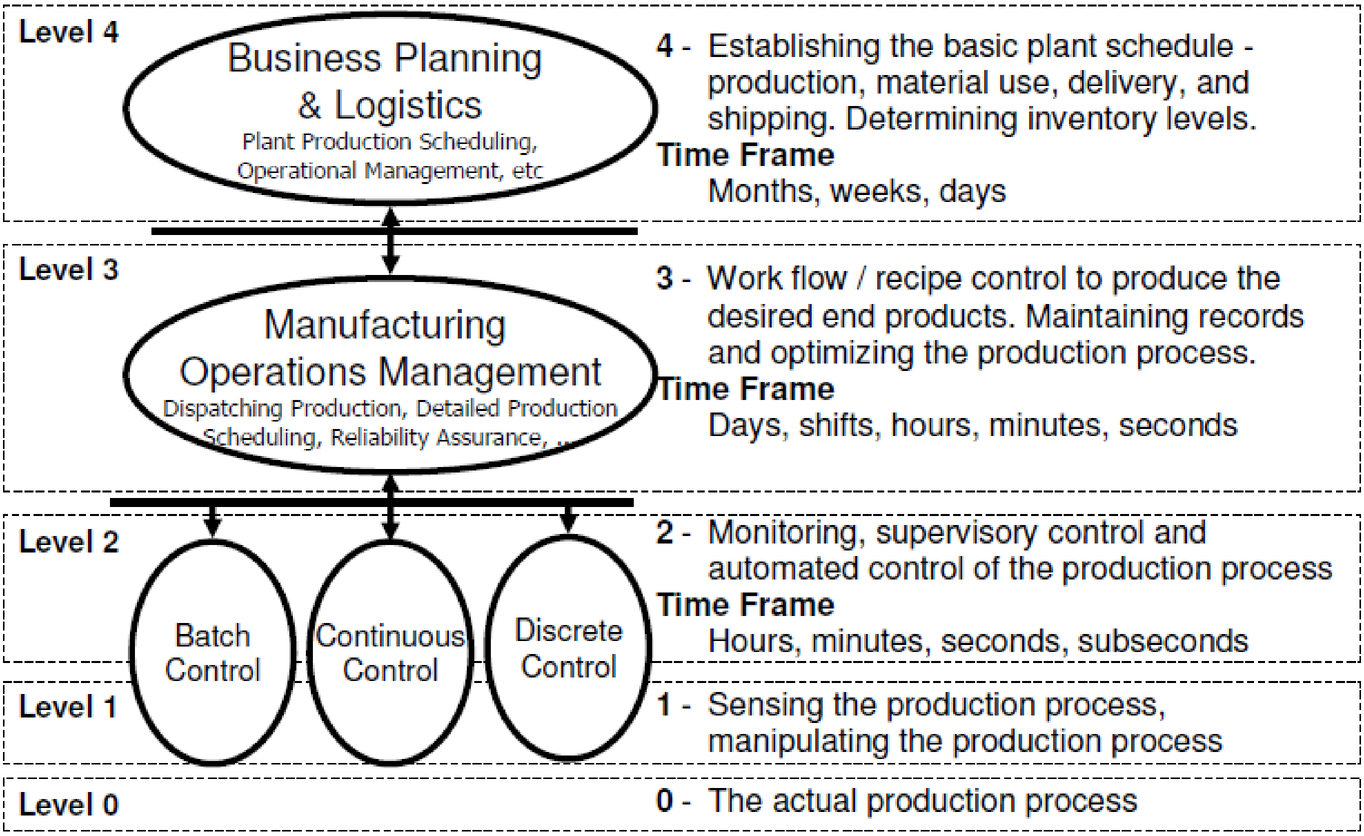


Figure 2-3: Functional hierarchy [17].

Integration between ERP systems and operational-specific applications like MES can be done in numerous ways depending on the desired outcome. RKL eSolutions [18] summarise four common methods for data integration with the Sage 500 ERP, but they can be applied to any ERP running on a relational database. These are:

1. File-based data exchange
2. Remote procedure invocation
3. Direct database integration
4. Messaging

They present the positive and negative aspects of each in Figure 2-4.

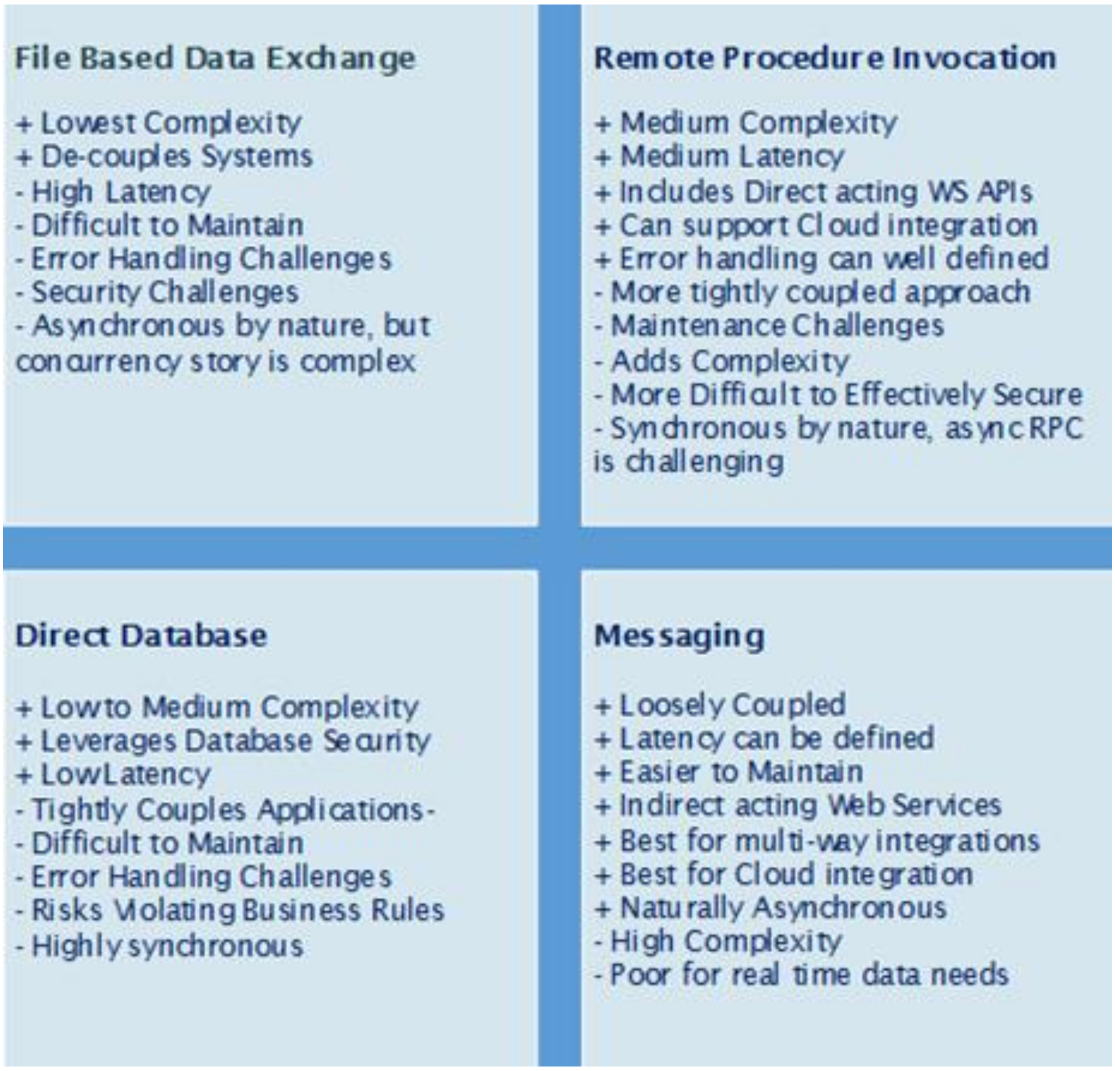


Figure 2-4: Four common ERP data integration styles [18].

2.3. Review of MES Structure

As defined before, MES are production oriented IT systems used to support, in real time, processes in complex or dynamic environments. Scholten [7] explains that due to unique requirements from various manufacturing operations, MES solutions will usually require some level of customisation. When picking vendors, an important aspect to consider is the amount of customisation that will be needed. To this end, she provides some useful tools for comparing customisation requirements between vendors.

Typical MES systems use object-based data models in order to manage the complex interrelationships between the various data parameters. This in turn leads to database requirements that are not typical of most business database models. Kappel and Vieweg [19] describe the key MES database requirements. They refer to the systems as Computer Integrated Manufacturing (CIM) but the functions they describe are predominantly those of modern MES. Their paper was written in 1994 when MES was still an emerging acronym. They discuss the following:

- **Data modelling requirements** (Figure 2-5) – Extended attribute domains, complex object support, relationships and dependencies, and active consistency checking and knowledge base support.

	Business databases	CIM databases
Data types	Few, simple	Many, complex structured
Relationships	Simple	Complex, highly dependent
Amount of data	High	High

Figure 2-5: Data modelling issues [19].

- **Querying and manipulation requirements** (Figure 2-6) – Advanced transaction management, flexible database access, change management, and interfaces.

	Business databases	CIM databases
Queries	Associative	Associative and navigational
Updates	Short	Long, highly interactive

Figure 2-6: Querying and manipulation issues [19].

- **Integration requirements** – Distributed data management, multi data management, reverse engineering of data, and integrated data and process modelling.

Meyer et al. [3] explain that to make their systems simpler to integrate into a company's existing structure, vendors will often aim to make their systems platform independent, scalable, and compliant with various integration standards. Scholten [7] adds that eXtensible Markup Language (XML) is currently the most modern method of exchanging information. Business to Manufacturing Markup Language (B2MML) is an XML based approach that uses metadata specified by ISA95 in order to make implementation intuitive.

2.4. Alternatives to MES

Christo and Cardeira [20] suggest that modern manufacturing systems (such as MES) require high investments, long lead times, and complex structures. This can lead to loss of flexibility, loss of reconfiguration capabilities, and high costs to make small changes. This is opposing to the needs of modern-day manufacturing. As an alternative, they highlight the potential of intelligent fractal, bionic, or holonic systems. They motivate the adoption of these systems, but recognise that there is still a need for further development in the fields of intelligent mechatronic components, software agents, and networks.

2.5. Review of BRM

The BRM methodology that will be applied in this research is based on Bradley [4]. Bradley's aim is to shift culture from using BRM to justify the business case to using it as a tool for driving benefits. He has compiled over 20 years of his company's experience into a detailed framework for approaching project, programme, and portfolio management. Bradley's approach BRM can be summarised as follows: BRM is a process that engages stakeholders in order to first identify the cause and effect relationships between the initiatives they are undertaking, the benefits they expect from these, and the company high-level objectives; and then to structure and measure the initiative with regard to the benefits.

The literature review found many additional views towards BRM which are worth noting in order to compile a broader picture of the methodology and its application:

- Jenner [21, p1] identifies "*a series of cognitive biases and organisational factors that adversely impact the production of accurate and reliable benefits forecasts and business cases*". He suggests that this is a reason that organisations struggle to demonstrate a return on their investments in change and therefore need more formalised strategies. BRM is one such strategy.
- Bolloni [22, 2] summarises the effect of BRM as follows: *"BRM provides a mechanism to lead the program always to be focusing on the business benefits to be realized, on the influencing factors and possible dependencies, on the required capabilities to achieve the stated objectives, and only at the end the technical solution is elaborated as a natural consequence of this progressive shift of thinking from the strategic objectives to the program deliverables"*.

BRM methodology can be adapted to various environments. Ashurst and Doherty [23] outline an approach for benefits realisation in IT projects. They explain the need for this by stating that IT development projects are traditionally looked at as technical rather than socio-economic change. This traditional approach fails to account for the necessary human and organisational changes needed to deliver meaningful benefits. They use the example of ERP introduction. Their approach is however generalised and could be considered for IT projects such as the introduction of MES.

A related note regarding adaptability to various environments. The desired outputs of the BRM process can vary based on an organisation's need. Figure 2-7 is a comprehensive benefits assurance review process as compiled by the Australian government [24]. It shows the review process along with the required outputs at each stage of an initiative.

Review Process		**Expected Key Benefits Documents**
Conception	At the beginning of a potential program, the Review Team will look to see that benefits have been identified and measures have been considered. The likelihood of achieving these benefits can assist a risk assessment for the program.	• Potential Benefits described • NPP • Submission
Pre-decision	Prior to reviewing a decision on a proposal, the Review Team will look for evidence that a benefits management approach has been applied, the agency is clear about what it wants to achieve and can quantify the improvements to be sought. Benefits that are able to be measured before delivery begins can be used as a baseline to compare improvements throughout the program. Benefits can be used in the business case to compare options.	• Business Case • Benefits Management Strategy • Benefits Profiles • Benefit Map • Implementation Plan
Implementation	During the implementation phases, the Review Team will look for evidence that the benefits agreed upon in previous stages have been incorporated and aligned to the delivery effort. Program success is more than meeting schedule, cost and scope. Programs should be able to show how their efforts and outputs contribute to benefits for the initiative. This can be achieved via a Benefits Realisation Plan. Some interim benefits may be achieved and reflected at these stages, increasing confidence of overall success.	• Business Case • Benefits Management Strategy • Benefits Profiles • Benefits Realisation Plan
Post Implementation	At this point in the life of the program, the Review Team seeks to ensure that the expected benefits that were envisaged earlier are being compared to measures taken following implementation of the new capabilities. In addition, the Review Team will also look to see how the management of benefits will be transferred into the agency for long term 'harvesting', bearing in mind that key benefits are often not realised at the time a program is closed.	• Updated Benefits Realisation Plan • Transition Plan • Program Closure Report

Figure 2-7: Australian government benefits assurance review [24].

There is evidence to suggest that BRM methodology is gaining popularity in the local (South African) environment. Marnewick and Labuschagne [25] have analysed the adoption of BRM as part of program management in JSE-listed South African companies. They conclude that while benefits management is only partially practised in industry, program managers are largely in support of introducing the theory.

Finally, it should be mentioned that literature also offers criticism of the BRM methodology. Breese [26] suggests that the BRM process is open to being played out in an ambiguous and contested manner which, in "the real world" may undermine the solid scientific framework on which it was designed. He comments [26, p34]: *"unless theories underpinning BRM develop beyond the scientific approach of the 'modern paradigm' there is a danger that BRM methods will fail to reflect the complexity of the management challenges facing organisations"*.

2.6. Alternatives to BRM for MES

In the introduction it is mentioned that MES implementations have traditionally been hampered by technical and organisational issues. The literature review has explained some of the ways in which the technical issues have been addressed. The organisational issues however have not been addressed as extensively. The book by Scholten [7] goes into more practical detail on what companies can expect from MES. She presents the Good Automated Manufacturing Practice (GAMP) "V model" as the accepted methodology for MES implementation. This is a technical approach that doesn't fully address organisational issues. She discusses a number of issues including scope, customisation, and acceptance by users. Her focal organisational concern is the blurred line between which organisational departments need to be responsible for the various aspects of the system.

While there are various potential approaches, the researcher is not able to find any comparative or best practise information. One example of an alternative methodology is presented by the information technology provider Cognizant [27]. They suggest that agile methods, like Scrum, are the best practise for MES rollout.

A paper that draws some similarities with the topic of this report is written by Liu and Chen [28]. They investigate Business Process Re-engineering (BPR) as a supplement to the technical implementation of CIM. This is an important paper because it recognises that CIM implementation is unique in that it requires elements of both “discontinuous” (step-like) and continuous process change. BPR is referred to here as a management discipline rather than a technical method; and it proposes similar outcomes to those proposed by BRM methodology. Similarly to BRM, BPR scopes implementation as requiring parallel process and system change. The approach to stakeholder management is also similar with both methods placing responsibility on employees directly involved in using or implementing the system. While the methods have similarities, they differ on how requirements are specified. The BPR method considered here places much design consideration on customer requirements. BRM on the other hand focuses primarily on company objectives, with cause and effect measurements being done more strictly than in the BPR method. While their paper is based on a case study, it does not mention the ultimate outcomes of the CIM implementation. It also does not segment MES from CIM in general. More information is therefore needed to perform a direct comparison between BPR and BRM for MES implementation.

3. THEORETICAL FRAMEWORK

The *“Literature Review”* chapter discusses the various considerations to MES systems. It converges onto the issue of integration, which while technically well defined, fails to adequately address organisation specific issues that commonly arise during the MES implementation. On a separate note, the *“Literature Review”* chapter discusses BRM methodology and its applicability in managing programs where technical and social considerations need to be dealt with in parallel. This chapter expands on BRM methodology, which is used in this case study, to implement MES at WMMEA.

From this point forward, any time that standard BRM methodology is mentioned, it will refer to the methodology as described by Bradley [4]. The chapter consists of two parts. The first summarises accepted standard BRM theory. The second part is an adaptation of this methodology, compiled by the researcher, for the purpose of MES system development and implementation.

3.1. Standard BRM Theory

BRM theory is well defined and extensive. For the purpose of this report, the researcher summarises the aspects of theory that are most relevant to this report. A summary of the key stages in the BRM methodology follows in sections 3.1.1 to 3.1.6.

3.1.1. Strategy Map

The strategy map outlines the goals of the company on a macro scale. These are goals such as compliance with certain environmental regulations, profit targets, or accreditation requirements. These would then be linked to numerous strategies which contribute to these targets in a cause and effect relationship.

The purpose of this map is to identify how the initiative under consideration will affect other initiatives and to direct the initial stages of the project. The strategy map is developed by the project (or programme) manager.

3.1.2. Stakeholder Management

In the context of this report, a stakeholder is defined as anyone who will be affected by or have a say in the proposed initiative. BRM places significant emphasis on stakeholders for a number of reasons:

- Stakeholders are experts in their respective fields and are able to define the best course of action.
- Stakeholders are able to steer the direction of the initiative in a planned or unplanned direction.

Stakeholders are to be identified by department. It is important to make sure the manager of each department is involved because the manager becomes the "benefit owner" of the system or process change for the department.

The aim at this stage in the process is to identify all perceived needs and issues (and only later determine if these needs can be satisfied by the proposed initiative). The outcomes of the stakeholder interaction step are to provide input for use in creating the benefits map (next step) and to identify benefit owners.

3.1.3. Benefits Map

The benefits map (also sometimes referred to as the benefits dependency map) is the key working document. While the strategy map outlines the various company objectives, the benefits map is initiative-specific and describes a path to the successful realisation of these strategic objectives.

While the strategic objectives might be measurable, it is often impractical to determine whether the achievement of the strategic goal is due to a specific initiative or due to factors outside of the scope of the initiative. However, the measured benefits on the benefits map are more directly related to the implementation of the initiative. The benefits map is created in three stages:

1. **The benefits.** These start from higher-level benefits that have a direct correlation with the strategic objective (likely to be the benefits that upper management would consider when creating the business case for an initiative). These then filter down to lower-level benefits (such as local department Key Performance Indicators (KPIs)) until they link in with the enablers in stage 3 below.

2. **The proposed system to be implemented.** The system's elements are described. Example: In the case of an ERP system implementation, this section would list the various modules that the system is comprised of (purchasing, warehousing, etc.).

3. **The business changes required to integrate the system into the company**, and so realise the benefit (this section is done in parallel with the solution management stage to be discussed below). These are the link between the systems and the benefits.

To make it easier for the user when creating the benefit map, BRM methodology recommends the use of colour coding for links, enablers, benefits, and strategic objectives. For example a blue link would indicate a positive relationship to the benefit and a red link would indicate a negative relationship (a dis-benefit).

3.1.4. Benefit Profiling

A benefit profile is created for each benefit. This includes a detailed description of the benefit, its related benefits, its target state, the benefit owner(s), and it specifies how the benefit is to be measured.

3.1.5. Solution Management

The solutions (or the enablers) then need to be detailed (before they can be implemented in a company to create positive benefits). The solution management template details the enabler, system change, supporting initiatives, benefit owners, and the associated benefits and dis-benefits. The enablers are then incorporated into the benefits map along with links to their associated benefits.

3.1.6. Benefit Tracking and Reporting

Benefits must be measured and monitored. The measurement criteria form part of the benefit profile.

- Ideally, benefits are defined in such a way that they are measurable (quantitative data). I.e. benefits are usually described with words like "increased", "reduced", "achieve", "maintain", etc.
- They are usually initiative-specific, meaning that any change in the measurement can be attributed to the initiative taking place.

It generally isn’t necessary to track each benefit, but the more benefits that are tracked, the easier it becomes to identify failure mechanisms and control outcomes. Tracking intermediate benefits makes it easier to pinpoint where in the benefits map problems (or broken links) lie. Typical deterrents to extensive tracking measures are time to implement and the cost of measurement.

3.2. Adapted BRM Methodology

In section 3.2.1 – 3.2.6 the researcher specifies his adaptations to the BRM methodology. This is done to make the method better suited for the specific case of MES system development and implementation. The researcher furthermore narrows the broad body of BRM knowledge into a specific, step like, methodology which can be applied in companies that do not have a BRM program. The adaptations in the methodology follow.

3.2.1. Strategy Map

The strategy map is not so much an adaptation as it is an extraction of the company strategy map. Using an extract shortens the process while still giving sufficient information to work with. This extract includes the strategic objectives that are the key focus of MES as well as any objectives which will be affected by (or have an effect on) MES. This is done to give the full picture of the cause and effect relationships in play during the implementation. This step is done by the project or programme manager. The resulting objectives will be used to develop the benefits map.

Note: the company objectives are set at the highest levels of management at the company, and are assumed correct. The setting of these objectives is outside the scope of this initiative.

3.2.2. Stakeholder Management

This section identifies the stakeholders typically affected by the MES system. It also details the recommended interaction with these stakeholders and the expected support from these stakeholders.

Scholten [7] explains that the ultimate ownership of MES systems lies with the production department. Responsibilities during implementation are however not clear. A focal point of BRM is to create benefit owners who are both responsible for and involved in daily system operation. The adapted methodology aims to identify the ultimate benefit owners up front so that they are not left out of the initial system justification and design. This way the ownership of the system is never passed over.

Stakeholders are identified by department and interactions are conducted via workshops. They are referred to as workshops rather than meetings because of the amount of participation and development that is expected to take place.

Regarding the initial workshops:

- They are department-specific and include at least one member responsible for each of the department's tasks. It is important to make sure the department manager is involved because he will become the MES benefit owner for that department.

- The context of the workshop is set, but the workshop should be conducted as a brainstorming session. The aim is to identify all perceived needs and issues, and only later determine if these needs can be satisfied by the MES system.

- The issues and needs are ultimately to be consolidated into themes and benefits. These form the issues and lower-level benefits sections of the benefits map (see *"Benefits Map"* section).

Regarding the subsequent workshops:

- These sessions are used to present the compiled benefits map to all the initial workshop participants.

- They are cross-departmental so as to put the map into context across the company.

- They provide a platform to do finishing touches such as closing any gaps that have been left open or resolving any clashing requirements that have been created.

- They create an understanding of the mechanisms in which MES will benefit the company.
- All this in turn will lay the foundation for the solution management section of the work (see *"Solution Management"* section).

The stakeholder list below is compiled by department. Each department will have a number of key stakeholders (those who will have an impact on the development or running of the system) and a benefit owner (the one who will be accountable for the realisation of the predicted benefits relating to his area of work).

- **General management**: This will typically be the project sponsor. General management is likely responsible for the final form and format of the strategy map. Note that general management does not need to be involved in the development and implementation of the system. General management will likely be responsible for the budget allocation and be interested in the higher-level benefits that the system will deliver.

- **Continuous improvement (lean or projects) department**: This department will take on the project management responsibilities of the MES implementation. They facilitate and provide resources. No system requirements should be specified by this department above what was developed in the workshops. Stakeholders at this level are:
    - **Project or programme manager (benefit owner):** Tasked with the continuous monitoring of all benefits and addressing major issues that arise.
    - **Process engineer(s) (key stakeholder(s))**: Tasked with assisting departments complete their projects. These will deal with project details, procurement, and interdepartmental collaboration. They also manage software development and collaboration with the software providers.

- **Planning department**: This department will be responsible for designing the system flow diagram (how information flows throughout the system) and for integration of planning (e.g. scheduling) systems with the MES system. Stakeholders are:
    - **Planning manager (benefit owner):** Tasked with ensuring company systems integrate with MES and with maintaining data integrity.
    - **Systems engineer(s) (key stakeholder(s)):** Tasked with integrating company systems with MES.

- **IT department**: This department oversees the enabling functions. They will provide hardware, software, and data (E.g. servers, terminals, user credentials, and supporting software). Stakeholders are:
    - **IT Manager (benefit owner)**: Tasked with approving and communicating the service agreement with the IT team.
    - **IT Support (key stakeholders)**: Tasked with responding to system requests.

- **Finance department**: This department is responsible for designing the system's hours reporting rules and procedures. They would ensure accurate integration between the MES and ERP (or other similar) systems. Stakeholders are:
    - **Finance (or costing) manager (benefit owner)**: Tasked with designing and auditing the costing integration process.
    - **Costing administrator(s) (key stakeholder(s)):** Tasked with capturing, reconciling, and reporting on the daily system outputs.

- **Machine shop production department**: This department will be the system owner. They are charged with the day-to-day operations of the system and ensuring that it runs at optimum capacity at all times. Stakeholders are:

- **Machine shop manager (benefit owner)**: Tasked with ensuring all applicable processes and procedures run through the MES system. He ensures that all the front line users are trained and enabled to use the MES system.
- **Machine shop administrator(s) or shift leader(s) (key stakeholder(s))**: Tasked with addressing day to day system issues, highlighting problems, as well as maintaining clean system data (housekeeping).
- **Machine shop operator(s) (key stakeholder(s))**: Tasked with the daily usage of the system as well as to participate in certain development activities.

3.2.3. Benefits Map

The benefits map (or benefits dependency map) (See template in Figure 3-1) is to become the key working document. Decision making and solution design will be based on the information on the map.

The benefits map is compiled as follows:

- The benefits map(s) is designed in an easily-sharable format (e.g. A3 format) to facilitate collaboration and present an amount of information that can be easily recalled by all stakeholders.
- The objectives that lead out of the strategy map are to be placed in the objectives section on the far right.
- The issues taken down during the workshops are summarised into issue themes. Each issue theme forms a block in the far left "issues" section. The individual issues that form that specific issue theme are summarised inside the block (these could also be looked at as a root cause with accompanying symptoms). The issues section replaces the traditional systems section, where a generic predefined system would typically be described. This section of the benefits map is the key adaptation of the map for the purpose of

MES development and implementation. This is because MES systems are not purely off-the-shelf products. They need to be highly customised towards the requirements and the infrastructure of the company. These customisations are scoped considering the issues that need to be resolved.

- The needs documented during the workshops are summarised into benefits and placed into blocks in the benefits section of the benefits dependency map. The benefits need to be measurable and have a preferred direction of change or a target. Benefits fall into three main categories. Lower-level benefits are those found within the MES system. Intermediate-level benefits are those that describe the outputs of the system. Higher-level benefits are the KPIs of a specific department.
- The benefits need to be linked by a cause-and-effect relationship, through higher-level benefits, to one of the desired business objectives. If they do not, then they are not benefits to those objectives (They may however still be spin-off benefits affecting an objective outside the scope of the project).
- A solved issue also needs to link to some benefit. If there is no benefit to resolving a perceived issue then it should be regarded as not a genuine issue and should be discarded from further consideration.
- The enablers form the links between the issues and the benefits. These are grouped by projects which will be defined in the *"Solution Management"* section. They are placed into blocks in the enablers section. Each enabler is composed of a number of required business and system changes. These are listed in a block for each enabler. A first draft of the required business changes and systems will have been developed in the workshops. These may be updated as the projects are elaborated. Note that this is the <u>second major</u>

adaptation of the benefits map for MES. It requires that the system and the business process get developed concurrently.

- The enablers are linked to issues and benefits using arrows. BRM methodology recommends the use of colour coding for arrows, enablers, benefits, and strategic objectives. The colour convention used is shown in the key in Figure 3-1; a template (developed by the researcher) for the benefits map.

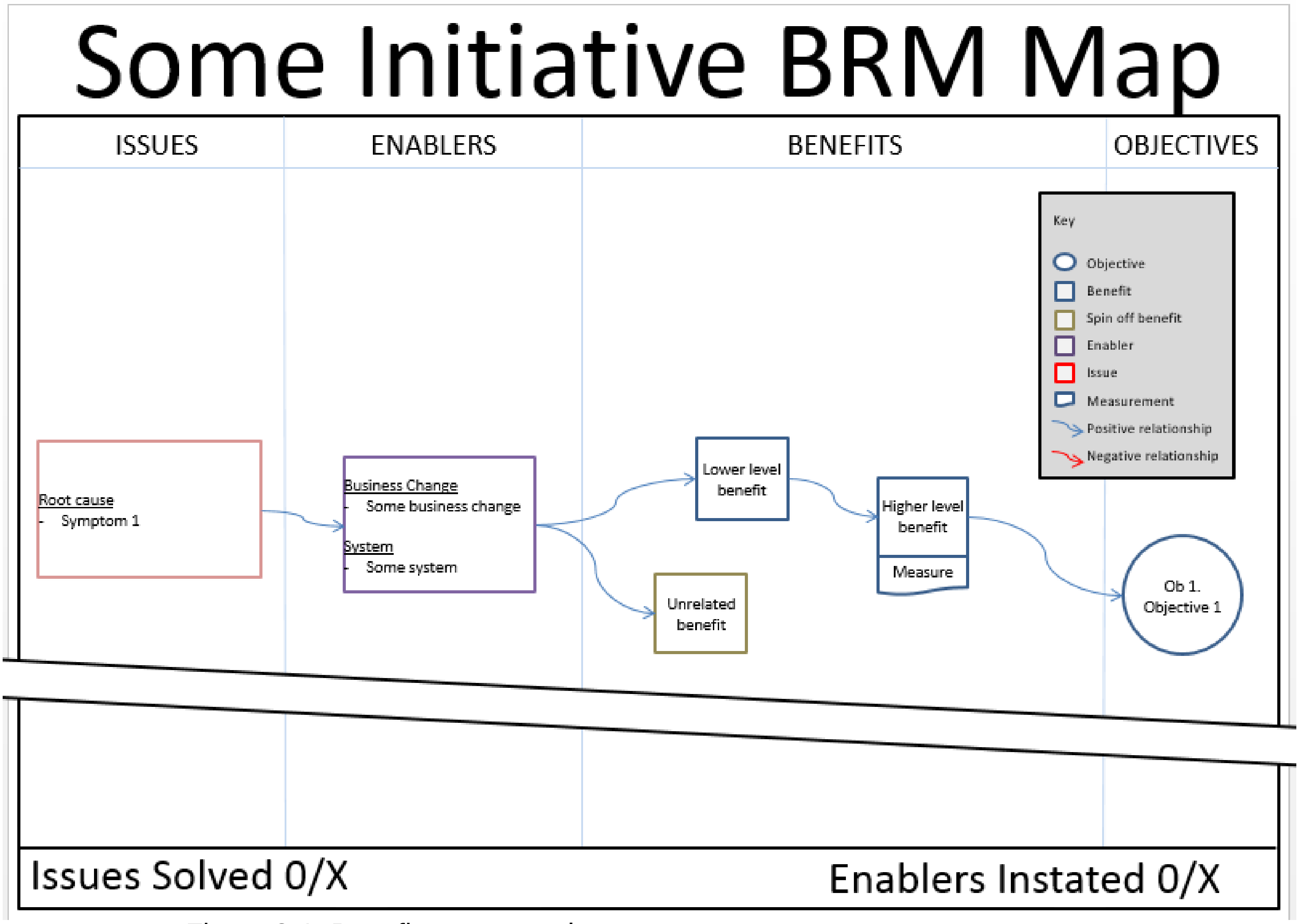


Figure 3-1: Benefits map template.

3.2.4. Benefit Profiles

A benefit profile serves to provide common understanding of how the benefit is defined. Each benefit needs to be profiled with the following detail:

- A description of the benefit. The benefits can be classed into either lower-level benefits (those that address MES software use or functionality), intermediate-level benefits (those that are due to MES usage), and higher-level benefits (typical production KPIs).
- Related benefits, both upstream and downstream benefits.
- External influences. These will typically be more complex to analyse on higher-level benefits.
- The measurement methods and parameters.
- The target state of the benefit.

The template (Figure 3-2) was developed for benefit profiling in the MES application.

Benefit Profile - (unique identifier)		
Short Description:	(gain, maintain, increase, decrease something)	
Explanation:	(give some background to what the benefit is, why it is a benefit, and how it influences the big picture)	
Preceding Benefit(s):	Preceding 1:	(short description)
	Weight 1:	(relative impact)
	Preceding 2:	(if applicable)
	Weight 2:	(if applicable)
Resulting Benefit(s):	Resulting 1:	(short description)
	Resulting 2:	(if applicable)
External Influence(s):	Influence 1:	(if applicable - detailed description)
	Influence 2:	(if applicable)
Measurement:	(explain what is measured, why, and how)	
Target:	(what is the ideal or targeted state)	
Data:	(graphical or tabular)	
Benefit Owner:	(name)	

Figure 3-2: Benefit profile template.

3.2.5. Solution Management

Solution management is an elaboration of the enablers described in the benefits map. The enablers are composed of the business changes (processes) and the systems that need to be put in place in order to solve the issues and create positive benefits.

Once the enabler is defined, projects (or work packages) are specified which aim to bring about the required business changes and systems.

These projects are summarised on a change action plan template (Figure 3-3). The purpose of the change action plan is to summarise and allocate the projects. It states all the business changes and requirements that the project will address as well as the key benefit(s) that will be achieved. The project is then allocated to the benefit owner(s).

One project may address multiple enablers or it may take multiple projects to address a single enabler. The template summarises each projects supporting project (or supporting initiative). The template in Figure 3-3 was developed specifically for the MES application.

Initiative Details:	
Initiative Identifier:	n/a
Initiative Description:	Some description
Document Creation Date:	XX-Xxx-XX
Document Continuity:	Sheet 1 of 2
Project Manager:	Mr X
Project Owner:	Ms Y

Projects Scope				
Project	**Description**	**Requirements**	**Business Change**	**System Change**
1. Name of first work package	A few short phrases that will give a feel for what the work package is about	The how	We will do this and this like this	We will use this and it works like this

Projects Scope				
Supporting Initiatives	**Unwanted Effects**	**Assumptions**	**Benefit**	**Benefit Owner**
Before we can get it right we will need to...	We must be aware of.. And mitigate...	Considering of course, that the world doesn't end tomorrow. This is why I think it won't	benefit 1 --> will lead to 2 --> will lead to our high level objective	Bobby

Figure 3-3: Change action plan template.

3.2.6. Benefit Tracking

The benefit measurement methodology, along with its desired direction of change, is defined in the benefits profile of each benefit. Measurement of benefits is highly dependent on a company's system structure and is not specified in detail in this methodology. The only requirement posed is that all measurement data needs to be quantitative.

Benefits however need to be tracked in relation to one another. The developed benefit tracking template (Figure 3-4) is used to carry out this tracking. Its purpose is to take the developed tracking measurements and places them in sequence from lower-level benefits to higher-level benefits. This allows the benefit owners to track, not only the individual benefit changes, but also the effect of a change in one benefit on another.

As far as possible, data will be structured to fit onto an x-y plot (with x representing a common time range) so that trends can be easily compared.

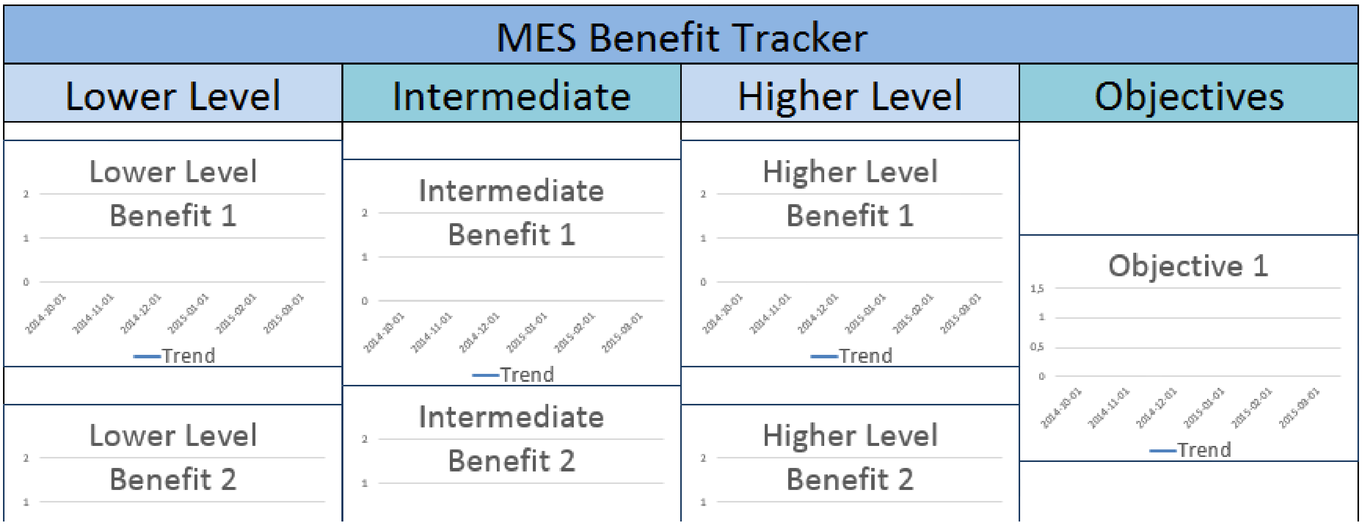


Figure 3-4: Benefit tracking template.

4. RESEARCH METHODOLOGY

The aim of this research report is to evaluate the validity of the BRM methodology for the implementation of MES systems at WMMEA. To do this, the most recent implementation of such a system at WMMEA is considered. It is important to note that the researcher evaluating the BRM methodology is the same person responsible for the adaptation and application of the BRM methodology at WMMEA. The researcher further supports the implementation by providing various stakeholders with the measurement data specified by the BRM methodology. While the researcher participates in the implementation (a contemporary event), he is not in control of many of the aspects of the event. With this in mind, action research could be considered as the research methodology. The following three additional considerations however suggest that case study research is the better suited methodology. Firstly, the research is an evaluation and not an exploration. As explained by McNiff and Whitehead [29], a major aspect of action research is the iterative action-reflection cycle (planning, acting, observing, and reflecting). This is contrary to the applied method which is based on a pre-existing framework. Secondly, the researcher's involvement in the implementation was circumstantial. The researcher could have conducted the research in the same manner had his role in the implementation been performed by a BRM practitioner. Thirdly, it is the researcher's feeling that the evaluative tools offered by Yin's [30] case study research methodology are more rigorous as well as better suited for the evaluation under consideration. This feeling is not the researcher's alone. In a paper comparing action and case study research, Blichfeldt and Andersen [31, p3] note: *"Several authors argue that action research should rely on the case-study method"*. In light of the circumstances described, the research method chosen is the <u>case study for evaluation</u>, where the researcher is positioned as a participant observer.

With regard to the adaptation of the BRM methodology; it should be noted that this is not a design report. While some aspects of the methodology were adapted to better handle MES system implementation, the fundamental concepts of BRM have stayed the same. It can be reasoned that since BRM is a generalised methodology, its application will have to, to some extent, be adapted to whatever situation it is being applied in. The adaptation is detailed in the *"Theoretical Framework"* chapter for the purpose of research reliability. The research is however concerned with evaluating the applicability of the BRM methodology.

4.1. Participant Observation

While a researcher as a participant in case study research is a common occurrence, the potential for bias needs to be addressed. This section will rely on the considerations presented by Iacono et al. [32]. Their paper is chosen because of the similarities in the environment the authors describes to the environment in which this research was conducted. She points out two sources of bias attributed to participant observation:

- The influence of the researcher on participant behaviour. In both cases; while the participants were made aware that the research was taking place, data collection was done discreetly during the course of business. Participants were professionals going about daily business in a professional environment.
- The impact of the researcher's beliefs on the findings. In both cases, there is a combination of enquiry from the inside and enquiry from the outside. All measurement data is quantitative (gathered from company records). This constitutes inquiry from the outside since the researcher is acting as a historian (gathering data over which he has no influence). The data demonstrates trends which are not open to interpretation. The researcher then (from the point of a professional within the company) discusses the results. This constitutes inquiry form the inside. In all situations where the researcher wishes to present his opinion regarding a result, he distinguishes his opinion from the result obtained. This is done in

situations where the researcher wishes to present an alternative explanation which he has no data to substantiate.

It is ultimately important to recognise that a participant observer role is not a less desired one. Conducting inquiry from the inside means that the researcher is able to put results into the context of company culture and business processes which an outside observer may not be privy to.

4.2. Case Study Methodology

This research is based on the case study methodology presented by Yin [30]. The following points reinforce the decision for selecting case study methodology as the research method for the evaluation:

- The research question is an empirical enquiry into a contemporary event with no clear contextual boundaries.
- The propositions derived from the research question require the identification of cause and effect relationships between benefits which are not mathematically defined.
- With specific regard to evaluations:
    - This case study details the initiative. I.e. how benefits were derived. To this point, Yin [30, p5319] makes the following statement: *"Because of the strength of case study research in capturing the complexity of a case as well as changes in the case over time, case study research is the conventional way for doing process or implementation evaluations."*
    - The previous point is related to the prediction of an outcome (I.e. the benefits). The second proposition requires the identification of the direction and change in magnitude of each benefit. To this point, Yin [30, p5352] makes the following statement: *"Case study outcome evaluations also can be useful when the outcomes of interest already have been identified. Now, the more challenging task would be to*

collect the outcome data and to draw conclusions about the direction or magnitude of the outcome trends".

4.3. Case Study Design

In order for a case study to be complete and satisfy the test for reliability (discussed later in this chapter), Yin [30] highlights the importance of setting out propositions and defining the case.

Two propositions are identified and detailed in the *"Propositions"* section of Chapter 1. In order to answer the research question, these propositions have to be shown to be true. The propositions are defined such that they can be addressed using the data the researcher aims to obtain. Furthermore, they are defined such that their validity will infer a positive answer to the research question.

The case (or unit of analysis) is the MES realignment project at WMMEA. It is detailed in the *"Case Background and Context"* section. All activity resulting from the project forms part of the case. External influences, while discussed, do not form part of the case. In order to maintain focus on the propositions, certain concepts had to be bound. Bounding is detailed in the *"Scope Delimitations"* section. MES is bound to a number of key functions (the functions present in WMMEA's system). BRM methodology is bound to exclude the ROI considerations. Limitations are put on the case study method. These are certain aspects of case study methodology which are important to ascertaining validity and reliability, but are not in the company's interest. Major uncontrollable events are discussed in the same chapter due to the limitations they impose on the research.

4.4. Data Gathering

Measurement of benefits is dependent on a company's system structure and is not specified in the derived methodology. In order to avoid biased tracking and measuring of benefits, all data gathered is quantitative. This means that the researcher is not put in a position where he needs to make a judgement (potentially insufficiently informed or open to interpretation) about the meaning of the data. Data gathering is to be done as follows:

- Where raw data is available (as historic, master, or transactional data stored on the company's main database), it will be mined directly and frozen as a snapshot at a set point in time. It will then be manipulated to satisfy the derived measurement's requirement.
- Only where raw data is not available, data will be gathered through primary observation (where the researcher notes what actually happened) of the parameter specified in the benefits tracking section of the BRM methodology.
- Only where raw data is not available, and direct observation is not possible, data will be gathered through structured interviews with the benefit owners. A structured interview asks all participants the same predetermined questions. For this research, the interview (per benefit) consists of asking the benefit owner (or a key stakeholder) a direct question regarding the state of the benefit. For example: *"What, in your expert opinion, is the current state of the benefit?"*

4.5. Linking Data to Propositions

The analytic strategy relies on the propositions derived from the research question. Because the propositions are based on interpreting quantitative benefits (as discussed in the theoretical framework), the selection of data to be used becomes synonymous with the data required to measure benefits. The situation is simplified by noting that quantitative benefit measurement is a BRM methodology requirement. This means that the data gathering task was handled in the implementation project itself and no further data gathering is called for by the propositions.

Three analytic techniques, Yin recommends [30, p3648], are employed in this research. Because BRM methodology is based on the principle of cause and effect, the *logic model* will be used to determine whether the predicted cause and effect relationships between benefits were valid.

Within the logic model, *pattern matching* has been used to identify the positive or negative prediction of individual benefits. *Chronological sequence time series analysis* is used both for explaining the behaviour of individual benefit trends as well as the relationship between benefits.

4.6. Interpreting the Case Study's Findings

This aspect of the work continues to rely on the proposition based analytic strategy. The outcome of the propositions is evaluated against the research question in a qualitative fashion. The researcher addresses issues of:

- Construct validity by discussing the selection of measurements and the approach to measurement.
- Internal validity by discussing convergence of evidence and rival explanations.
- External validity by discussing the adaptations made to the BRM theoretical framework.
- Reliability by discussing the research protocol and case study database.

Based on this, an answer to the research question is presented.

4.7. Ethical Considerations

Ethics clearance was obtained from the School Ethics Clearance Committee (ethics clearance number: MIAEC 046/15). Key ethical considerations addressed are:

Permission to do research – In order to conduct the research certain data had to be made available to the researcher and certain extracts from this data have to be presented in this report. Furthermore, the research will to an extent involve interaction with certain employees. Written permission was given by the factory manager for the research to take place.

Data collection methodology from human participants – The majority of data was gathered through data mining on the company database. Certain data was however not stored formally by the company and was acquired through structured interviews. The participants were selected based on their participation in the MES development and implementation. Data from participants was collected through a formal questionnaire. The purpose of the questions is to identify trends in data and not to gather personal information. Participants were told that the researcher is gathering information for the purpose of this research. A simple verbal explanation was given of the purpose of the questionnaire and was followed by a sign off on the information given.

Confidentiality and anonymity – The company has approved this questioning. Participants were told (and signed on the questionnaire in agreement) that confidentiality and anonymity would not be given. Confidentiality is not considered because the data gathered is a direct requirement for deriving the results of this report. No sensitive data was requested. Anonymity is not guaranteed because positions are such that only one person could have answered those questions.

Due to the large volume of raw data, all raw data used (including signed questionnaires) is available on the digital media accompanying this report.

5. RESULTS

This chapter summarises the data gathered for the purpose of satisfying the two propositions laid out.

5.1. Results – Proposition One

The first proposition serves to confirm that the specified BRM methodology was, completely, applied in the "real world" context (i.e. in this case study). Completely, in this case, implies that all the steps specified in the *"Adapted BRM Methodology"* section were performed at the company.
As stated in the *"Propositions"* section, this proposition focuses on the initiative. Rather than simply ticking off a list of deliverables (from each step), the researcher aims to give the reader a "feel" for the real events that took place during the implementation. The approach taken is to do this by detailing the deliverables derived by the stakeholders in the initial, workshop, and project execution stages of the BRM methodology.

5.1.1. WMMEA-Specific Strategy Map

The strategy map (Figure 5-1) is derived from the WMMEA company-wide deployment policy. Only the nodes of the map which were the focus of the MES implementation and the affected adjacent nodes are mapped.

The two downstream nodes which the implementation will address are:

1. **Increase Make-To-Stock (MTS) availability and On Time Delivery (OTD) to customer** – Availability is a measure of "is MTS classified stock available on the shelf at the time when the customer requires his delivery" and OTD is a measure of "has an MTO part been delivered to the customer in the time promised to him".

   These are high-level company objectives which can be traced down to the performance of the machining operation (i.e. the measurement is filtered on internally machined parts only). The company target for both of these measures is 89% (as of 1st February 2015).

2. **Increase output value** – Because the machine shop doesn't sell at a profit, it uses throughput rate to determine how much value it is generating for the company. Throughput rate is a monetary value-per-hour generated measure on parts where there is genuine short-term demand. It is used to ensure that the highest quantity of the most profitable parts is made. Increase in throughput rate is a temporary measure as an increase will ultimately result in a cost-roll (readjustment of standard run times) for the affected parts. There will be no cost-roll over the term of the measurement in this report.

It should be noted that strategic objectives are usually affected by numerous activities throughout the company and that a change in their measure may not be entirely related to the activity under investigation. The strategy map shows two major upstream objectives which will have an impact on the measured objectives described.

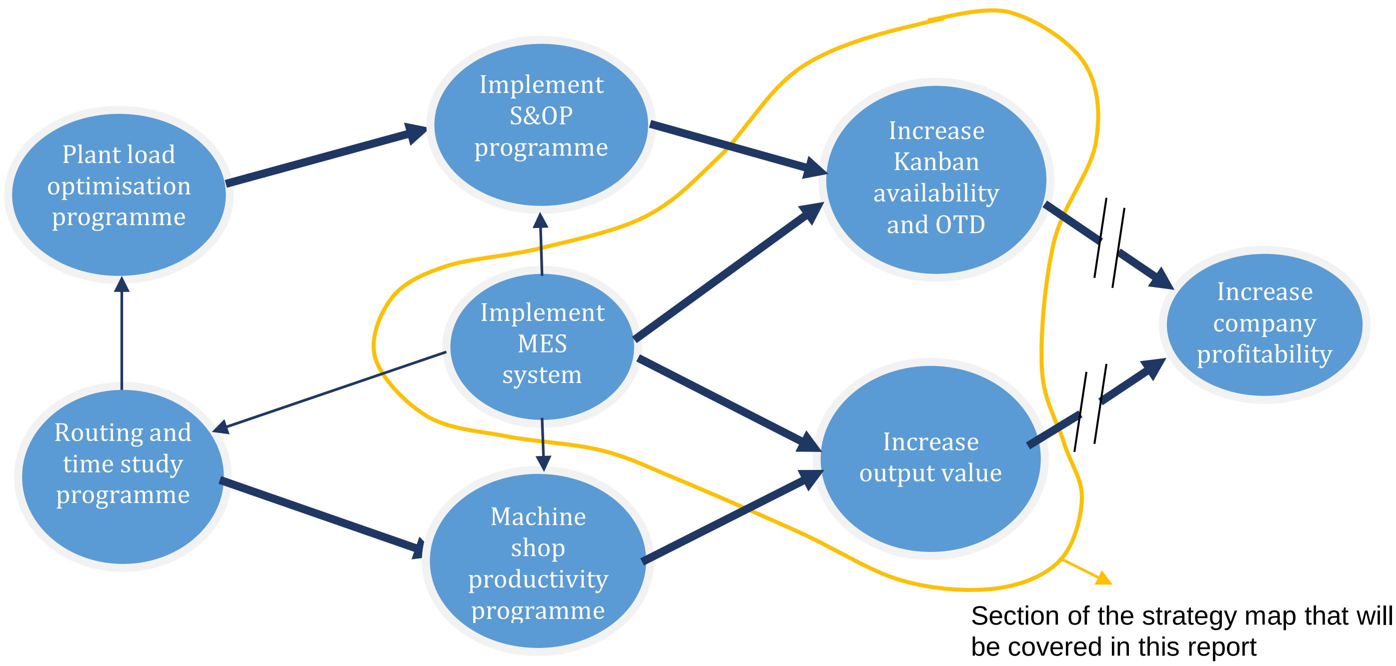


Figure 5-1: WMMEA derived strategy map extract.

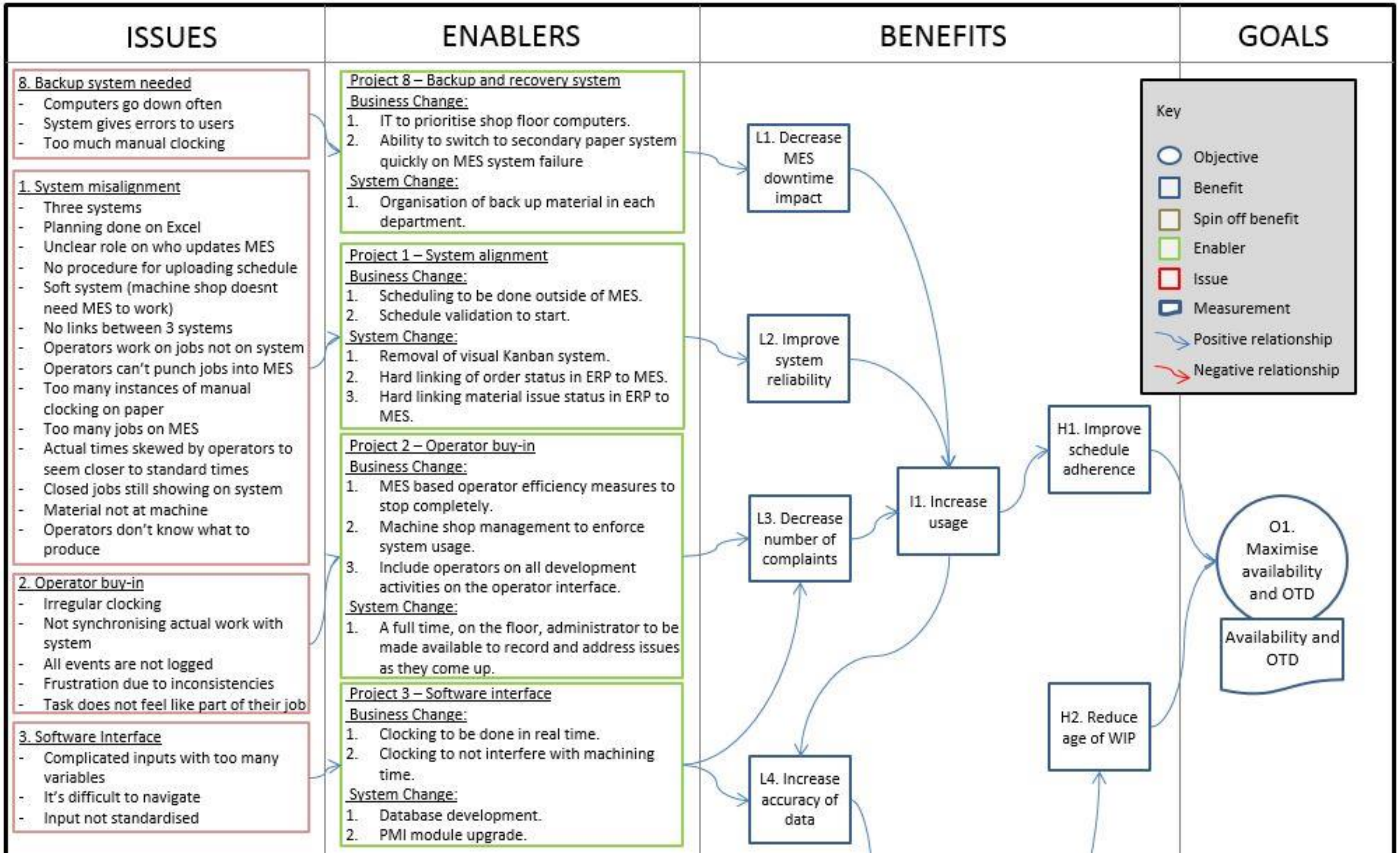
5.1.2. WMMEA-Specific Benefits Dependency Map

The benefits map in Figure 5-2 was derived in workshops which are detailed in the *"Adapted BRM Methodology"* section. The following outcome are noted:

- A total of 48 unique issues were summarised into 8 themes (or root causes).
- A total of 15 potential benefits were identified (7 lower-level, 4 intermediate, and 4 higher-level). 1 spin-off benefit was identified.
- A total of 8 enablers were specified (comprising of 20 business changes and 13 system changes).

The rest of this section details how the issues and benefit profiles were compiled. The enablers are detailed in the *"Solution Management"* section that follows.

MES System BRM Map



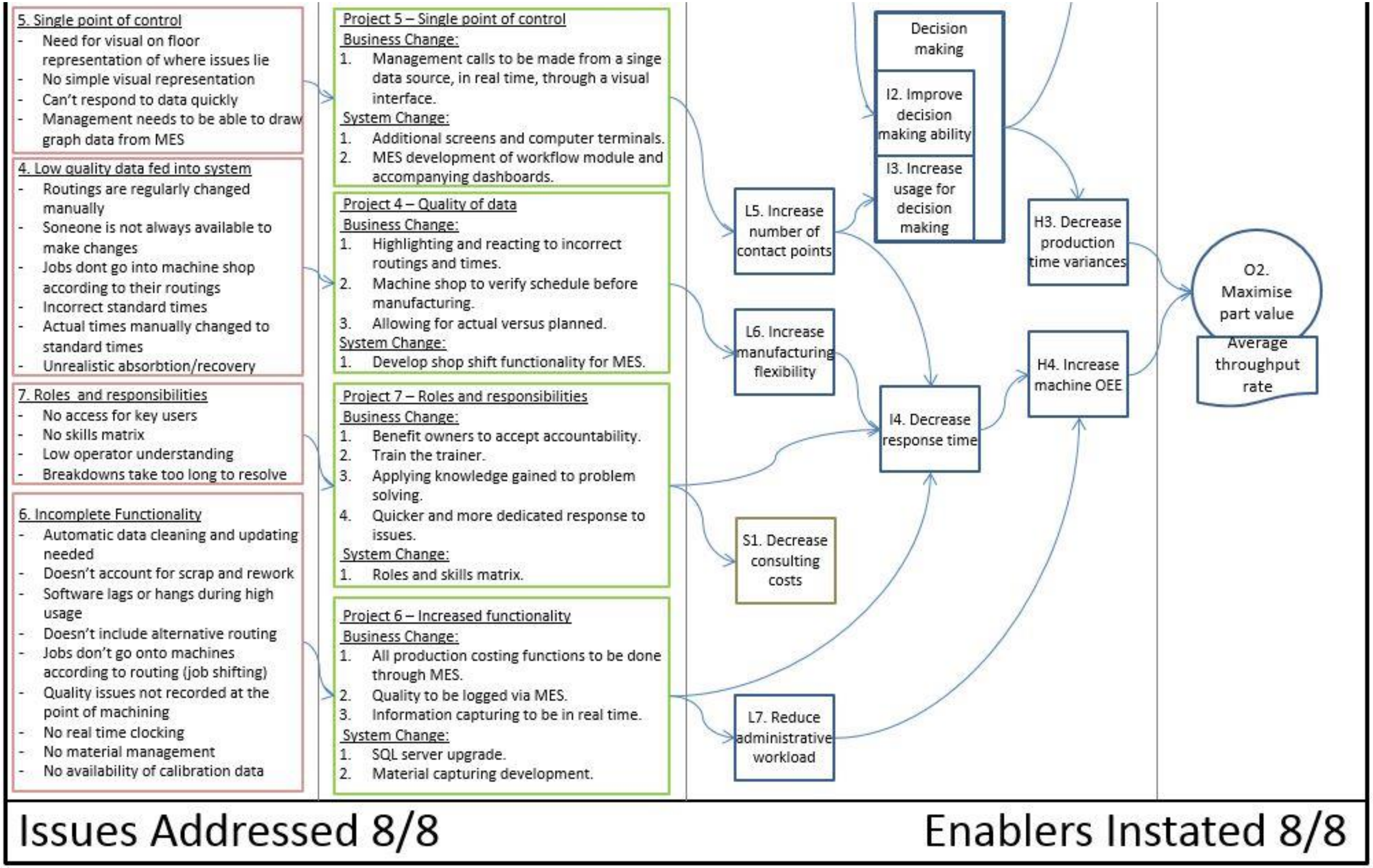


Figure 5-2: Machine shop benefits map.

Issues

The eight issue themes (or root causes) were identified as follows:

- System Misalignment
- Operator Buy-in
- Software Interface
- Low-Quality Data Fed Into the System
- Single Point of Control
- Incomplete Functionality
- Roles and Responsibilities
- Backup System

The first of these, *"System Misalignment"*, is representatively shown here. All eight are included in *"APPENDIX A: Issue Themes (Root Causes)*".

System Misalignment

The perceived symptoms for this issue theme (as they were described in the workshops) are summarised in Table 5-1.

Table 5-1: System misalignment symptoms

Multiple Systems: Three separate systems, auxiliary to the ERP, are used to manage production. They do not communicate between themselves.	Planning done in Excel: Most of the communication from the planning department is distributed through non-standard Excel spreadsheets.	Unclear role on who updates MES data: There is no designated person or standard operating procedure.
No procedure for updating schedule: There are no set rules and timelines for production schedule release.	Soft system: Machine shop does not need MES to function. Urgent or inconvenient work can bypass MES.	No systems link: There is incomplete communication between systems. Data regularly has to be transferred manually.
Operators work on jobs not available in MES: Jobs that are delivered to or selected by operators are not planned in MES.	Operators can't punch jobs into MES every time: Various technical issues prevented the clocking of jobs into MES.	There are too many instances of clocking on paper: Where an operator cannot (for any reason) clock work on the MES system he will instead just note it on paper.
Too many jobs in the MES: Invalid work is entering the system making navigation difficult.	Actual times are skewed by operators to seem closer to standard times: Operators can cheat on their performance figures by entering any time values they chose.	Completed jobs showing in system: Jobs previously completed by the operator are returning to MES and showing as to-be-machined.
Material not at machine: There is no material available for the job which MES specifies as next in line.	Operators don't know what to produce: Operators receive so many mixed messages that they no longer know what they need to produce.	

It was identified that three distinct systems (see Figure 5-3) supplemented the MRP with scheduling, shop floor control, and production execution. There was no logic dictating flow or interrelationship between the systems. Furthermore, there was no hard link between MES and any other system. Using the original (more entrenched) systems, MES could be completely bypassed.

Figure 5-3 shows that work instructions did not have to pass through either the Kanban or MES system before machining. This is depicted by no solid black arrow link (these links are required and the process cannot continue without them being actioned). On the other hand, unavoidable soft links are depicted as dashed black arrows (the overall process can continue without the link being actioned, but the operations following that link cannot be), and avoidable soft links are depicted as red arrows (both the overall process and the operations following the link can continue without them being actioned). The MES system is linked entirely by dashed arrows and runs in parallel with Kanban system. The ramification of this is that when only some of the production data is captured by each system, neither of the systems is able to accurately account for the current state of production. This can be reconciled by the ERP but the process falls behind real-time by a number of days making the information far less valuable once it is finally made available.

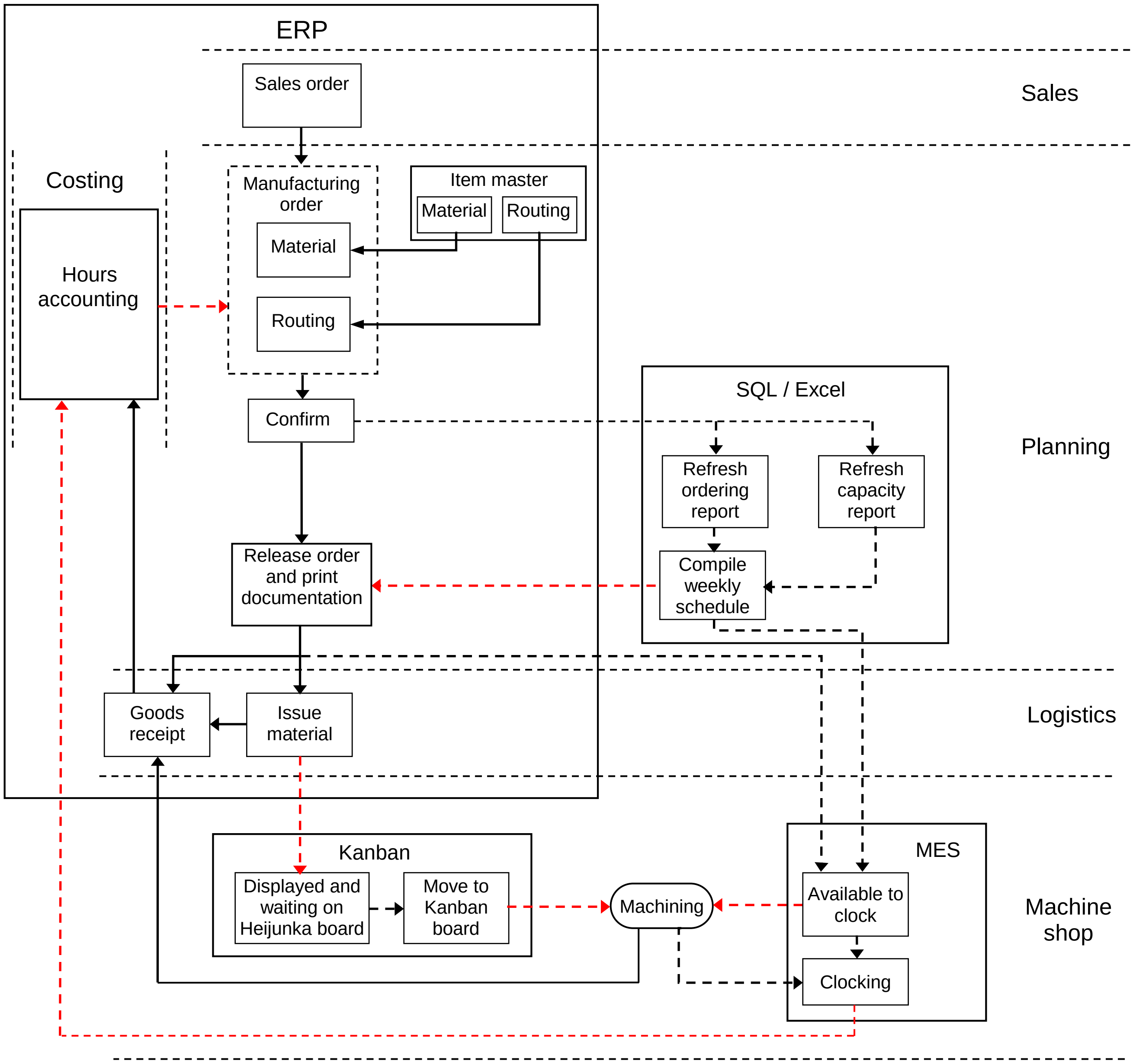


Figure 5-3: Production systems diagram (original state).

Benefit Profiles

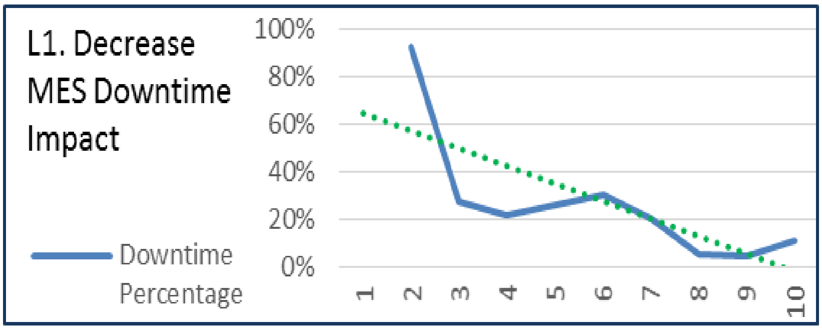
Starting from lower-level benefits up to the strategic objectives, a detailed definition of each benefit and objective, on the Benefits Dependency Map, is created. Weightings are estimated during initial workshops.

The first of these, *“L1. Decrease MES downtime impact”*, (Figure 5-4) is representatively shown here. All seventeen are included in *“APPENDIX B: Benefit Profiles*”.

<table>
<tr><th colspan="3">Benefit Profile – L1.</th></tr>
<tr><td>Short Description:</td><td colspan="2">Decrease MES downtime impact.</td></tr>
<tr><td>Explanation:</td><td colspan="2">It is expected that due to a number of unavoidable factors, the MES system will occasionally become either partially or completely unavailable. These downtimes will in turn have a negative impact on the system usage. Some common causes of system downtime are power surges, network availability, hardware crashes, software crashes, slow response to repair, incomplete user profiles, and untrained users. To be classified as downtime, the system must be completely unusable by the operator.</td></tr>
<tr><td rowspan="2">Preceding Benefit(s):</td><td>Preceding 1:</td><td>Enabler. Project 8 – Backup and recovery system.</td></tr>
<tr><td>Weight 1:</td><td>100%</td></tr>
<tr><td>Resulting Benefit(s):</td><td>Resulting 1:</td><td>I1. Increase usage.</td></tr>
<tr><td rowspan="2">External Influence(s):</td><td>Influence 1:</td><td>None.</td></tr>
<tr><td>Weight 1:</td><td>n/a</td></tr>
<tr><td>Measurement:</td><td colspan="2">Downtime is measured as a percentage of operators who used the system per shift versus the total number of operator shifts in the given time period. The measurement is based on the fact that had the system been “up”, the operator would have captured something within the shift. Having had not captured anything (but still reported having done work) reliably implies that the system was not available for him to use.</td></tr>
<tr><td>Target:</td><td colspan="2">Decrease downtime.</td></tr>
</table>

Data:

Period	Downtime Percentage
1	#N/A
2	92%
3	27%
4	22%
5	#N/A
6	30%
7	20%
8	5%
9	4%
10	11%



Benefit Owner:	Machine shop manager.

Figure 5-4: Benefit L1. Decrease MES downtime impact.

5.1.3. Solution Management

A set of eight projects (Figure 5-5) was compiled in order to instate the required enablers. One project was devised for each enabler, each addressing one of the issue themes outlined above.

- System Alignment
- Operator Buy-in
- Software Interface
- Low-Quality Data Fed Into the System
- Single Point of Control
- Increased Functionality
- Roles and Responsibilities
- Backup and Recovery System

The projects were then delegated to the benefit owners and sequenced to determine the timing plan of the projects.

Initiative Details:	
Initiative Identifier:	n/a
Initiative Description:	MES Realignment
Document Creation Date:	28-Oct-13
Document Continuity:	Sheet 1 of 1
Project Manager:	Project manager
Project Owner:	Machine shop manager

WEIR MINERALS

Projects Scope									
Project	**Description**	**Requirements**	**Business Change**	**System Change**	**Supporting Initiatives**	**Unwanted Effects**	**Assumptions**	**Benefit**	**Benefit Owner**
1. System alignment	Production is planned, scheduled, and executed via a number of systems. According to the systems diagram, redundant systems need to be eliminated, and hard links need to be made between the systems that remain.	"> Revise the systems architecture. > Revise each department's process flows. > Assign responsibilities. > Update scheduling software. > Remove Kanban system.	> Scheduling to be done outside of MES. > Schedule validation.	> Removal of Kanban system. > Hard linking order status in ERP to MES. > Hard linking material issue status in ERP to MES.	> Scheduling considerations from the new S&OP programme.	> Extensive troubleshooting with insufficient manpower. > Subcontract planning will have to be done via a separate system.	> There is agreement to eliminate the Kanban system.	Key Benefit --> L2. Improve system reliability.	Planning manager
2. Operator buy-in	The goal is to make the operators of the MES system want to use it over any other potential system. They need to understand the purpose of the system and the need for consistent accurate input. In order to do this, the company needs to address their complaints and recommendations.	> Address complaints and recommendations. > Make sure that there is an outcome from addressing each issue. > Motivation and enforcement.	> MES based operator efficiency measures to stop completely. > Machine shop management to enforce system usage. > Include operators on all development activities on the operator interface.	> A full time, on the floor, administrator to be made available to record and address issues as they come up.		> Excessive customisation.		Key Benefit --> L3. --> I1. Increase usage.	Machine shop manager
3. Software interface	A lot of operator frustration is related to the interface with which they operate regularly. An interface needs to be created which will both encourage regular accurate input and minimise the time spent capturing.	> Clear scheduled list. > Show only issued orders. > Minimise clicks and options.	> Clocking to be done in real time. > Clocking to not interfere with machining time.	> Database development. > PMI module upgrade.	> Communication with other plants to scrutinise their interfaces.	> Loss of system stability.	> MES software developer will be willing to do development on established modules.	Key Benefit --> L4. Increase accuracy of data.	Process engineer
4. Low quality of data	Correct routings and correct standard times are needed for MES to control production. They need to be updated. In addition the MES system can be adapted to be more flexible with what it can capture at the machine interface.	> Update routings. > Update standard times. > Extract variance data from MES. > Find method for shop shifting.	> Highlighting and reacting to incorrect routings and times. > Machine shop to verify schedule before manufacturing. > Allowing for actual versus planned.	> Add shop shift functionality to MES.				Key benefit --> L6. Increase manufacturing flexibility.	Process engineer

Projects Scope									
Project	**Description**	**Requirements**	**Business Change**	**System Change**	**Supporting Initiatives**	**Unwanted Effects**	**Assumptions**	**Benefit**	**Benefit Owner**
5. Single point of control	For each department or area there needs to be a unique, MES based, dashboard that provides sufficient info for day to day management. It should be visible, flexible, and contain enough information to remove the need for alternative systems.	> Screens and display material for the planning, logistics, and machine shop departments.	> Management calls to be made from a single data source, in real time, through a visual interface.	> Additional screens and computer terminals. > MES development of workflow module and accompanying dashboards.				Key benefit --> L5. Increase number of contact points.	Process engineer
6. Increased functionality	In order to be able to fully perform its main functions, the MES system needs a minimum set of features. Gaps have been identified in functionality that should be addressed. These centre on real time information, completeness of information, material, and system speed.	> Database development. > Quality function. > Material integration with ERP. > Hardware and software upgrades.	> All production costing functions to be done through MES. > Quality to be logged via MES. > Information capturing to be in real time.	> SQL server upgrade. > Material capturing development.	> IT to upgrade infrastructure to accommodate new function.		> IT will accept the task of upgrading the system infrastructure.	Key benefit --> I4. Decrease response time and L7. Reduce administrative workload.	Process engineer
7. Roles and responsibilities	When all responsibility falls on a person or department which is separated from where the system is being used, quality and speed of response deteriorates. It also becomes difficult to obtain all the necessary knowledge to troubleshoot and maintain. The cost of external consultation also increases significantly. The ability to train and troubleshoot internally is therefore important.	> The system needs to be self-sustaining. > A MES process map needs to be derived and people identified who are able to managing each link. > Employees need to have detailed knowledge and backup should they not be available. > Internal training is required.	> Benefit owners accept accountability. > Train the trainer. > Applying knowledge gained to problem solving. > Quicker and more dedicated response to issues.	> Roles and skills matrix.				Key Benefits --> I4. Decrease response time.	Each department's manger
8. Backup and recovery system	Once the Kanban system is removed, MES will be the main shop floor control system in the machine shop. This is a computer based system and is susceptible to power outages, network availability, and hardware breakdown. A backup system must ensure that machining will not stop in case of MES system failure.	> There has to be a ready to run alternative system which can be activated the moment the MES system fails. > No trend data should be lost.	> IT prioritises shop floor computers. > Ability to switch to secondary paper system quickly on MES system failure.	> Organisation of back up material in each department.		> The backup should not be used unless necessary.		Key Benefit --> L1. Decrease MES downtime impact.	Machine shop manager

Figure 5-5: Change action plan for MES.

Solutions Management Projects

As noted above, there were eight Solutions Management projects. Since this report is focused on BRM methodology and not project management methodology, it will not go into full detail on how the projects were carried out. Rather, it focuses on the reasoning behind the projects and their outcomes.

The first of these, *"System Alignment"*, is representatively shown here. All eight are included in *"APPENDIX C: Solutions Management Projects*".

<u>System Alignment</u>

This was identified as the largest contributing factor for the lack of system usage by operators. Even if all other enablers were instated, the MES system would be unable to perform as part of the company's macro system without being aligned with other systems.

The project resulted in the cessation of the Kanban system and hard-linking of the remaining systems to create a new workflow. Figure 5-6 shows the systems diagram after the project has been completed (this is the revised systems diagram, Figure 5-3, from the *"Issues"* section). It was achieved as follows:

- The Kanban system existed prior to the MES system, but was not considered in the initial MES implementation. The system remained and was run in parallel with MES. This not only created a duplication of work but made both systems unreliable (the Kanban system can no longer signal for work reliably as it doesn't have a way of knowing what work MES is signalling, and vice versa). With this setup, MES becomes just an administrative task which can be bypassed by simply not using it. This is an example of a disbenefit that was created by MES. The Kanban system had to be made obsolete.

- Hard linking of systems is done to prevent execution of certain system operations while bypassing others (an example would be a printer which doesn’t allow printing without the paper tray being loaded first). Automation is also a consequence of hard linking. The hard links created in this case were:

- o Between the scheduling system and ERP
- o Between ERP and MES
- o Between MES and the machining operation

The resulting process is summarised as follows:

- ERP generates orders
- All orders have to be scheduled in the scheduling system
- Scheduling system writes the schedule to ERP
- ERP releases the scheduled (sequenced) orders to MES
- MES dictates machining and material flow
- MES feeds the results back to the ERP costing module

In Figure 5-6, hard links are shown as solid black arrows (these are required and the process cannot continue without them being actioned) and avoidable soft links as dashed red arrows (both the overall process and the operations following the link can continue without the previous being actioned). The new red link is a backup in the event that the MES system fails.

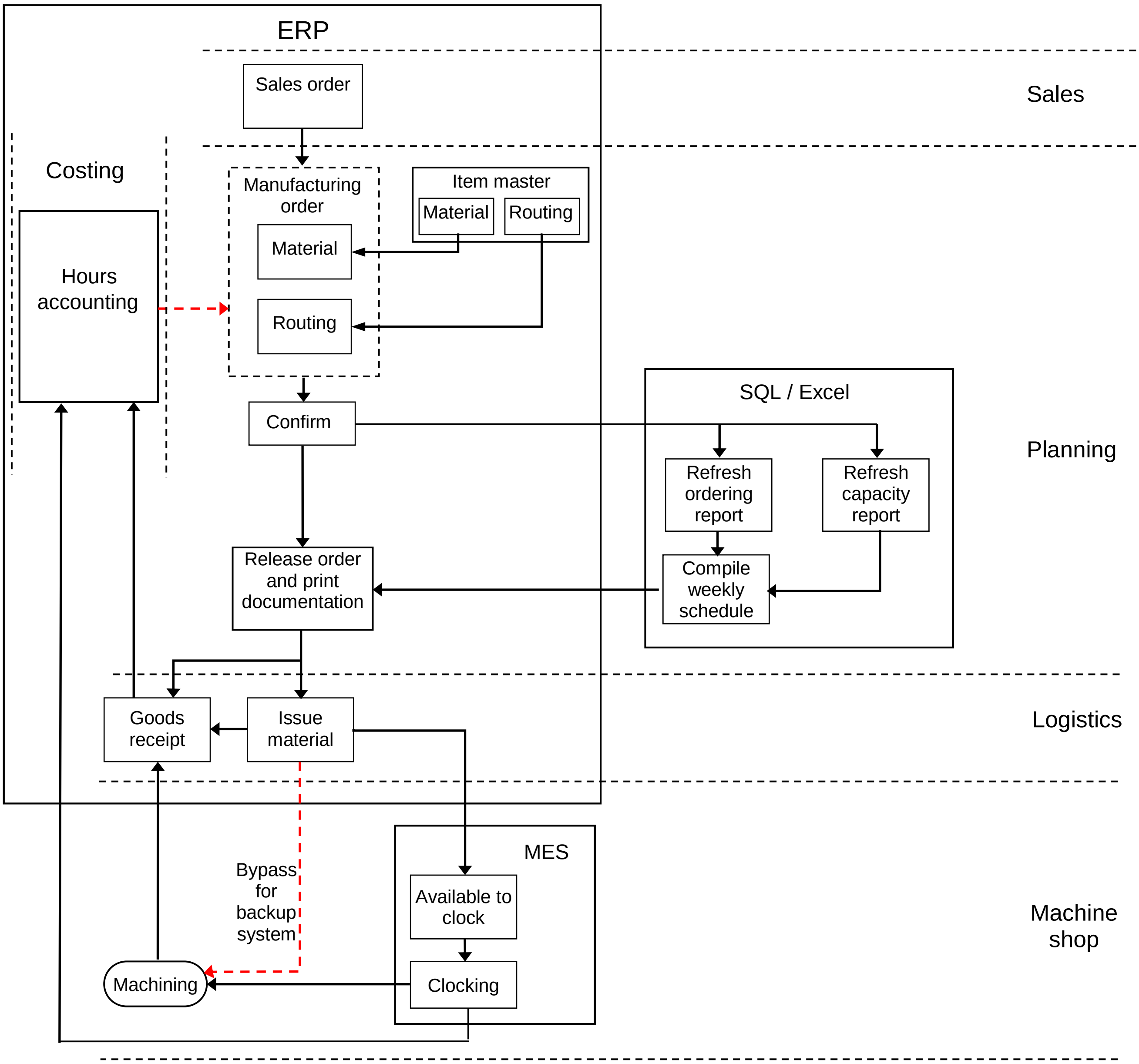


Figure 5-6: Preferred (end) state systems diagram.

Sequence and Delegation

Projects were delegated to benefit owners based on the affected lower-level benefits for which they are responsible. Sequence was based on the specific outcomes of each project. Where resources allow, projects can overlap. The sequence was as follows:

1. **Single point of control:** This was chosen as the starting project because its outcomes ensure all stakeholders have access to the system's outputs at all times at all points. This visibility sheds light on system flaws and inaccuracies. It also places pressure on all parties for the timely completion of the projects to follow.

2. **Backup system:** This was a prerequisite for both getting rid of the original system and for monitoring the usage and uptake of the new system. For example, the number of occasions where the backup system has been used is a direct indicator of where the new system has failed. The company can analyse these events and strive to reduce their frequency.

3. **System alignment:** The first and largest systems modification. It eliminates the previously-used Kanban system and lays the ground work for any other system developments. Any developments made before system alignment will fail to work reliably.

4. **Software interface, incomplete functionality, and operator buy-in:** These were all grouped together because they share an implementation process. In order to change both the interface and to add functionality the software developers had to be brought in to reprogram the software. At the same time operators worked on testing and providing feedback on the developments.

5. **Low quality data fed into the system:** This project requires the system to be running and gathering data.

6. **Roles and responsibilities:** This project aims to entrench and improve on the above developments.

5.1.4. Benefit Tracking

Benefits are gained or lost throughout the MES system development and implementation. Each benefit's measurement requirement is specified in its benefit profile. The benefit tracker is a template that consolidates the measurements of all benefits and company objectives. It is populated continuously throughout the initiative and used to measure the success of the initiative, as well as areas of concern which need to be revisited.

Figure 5-7 shows the benefit tracker as it looked at the point in time when this report was compiled. On each graph, a green trend line signifies a change in the predicted (desired) direction. A red trend line signifies the opposite.

The following immediate observations with regards to measurement data can be noted:

- It is possible to ascertain a trend for all 15 benefits and both company objectives.
    - Benefit measures all have between 5 and 10 data points.
- 14 of 15 benefit measurements have a trend in the predicted direction.
- Both measurements of the company objectives trend in the predicted direction.

Before ending this section, a few comments should be made on the <u>selection of time periods</u> (summarised in Table 5-2):

- Period 1. A version of the MES system did exist at WMMEA for many years prior to the initiative described by this case study (the initiative launched in November 2013). The system was however not in use. From the start of the initiative until 10 March 2014, the system was mainly used for investigative purposes.

- Period 2. The start of this period (10 March 2013) coincides with the company's implementation of a new ERP system. Most data before this period was either deleted or achieved, making data mining impractical. The more significant implication of the ERP introduction was that it resulted in the majority of the MES system having to be turned off for roughly three months. The system was slowly restored towards the end of June 2014.

- Period 3. Strike action in July brought the machine shop to a halt for 4 weeks. The system was running but all focus was shifted towards recovering from the strike action. The researcher estimates this period to have lasted until October 2014.

- Period 4. Some focus was placed back onto the MES initiative but many key stakeholders were unavailable, "chasing end of year targets" that the company had fallen behind on due to the two events mentioned above. The company began to close its operations from 12 December for the end of year holidays.

- Periods 5 to 10. Complete focus was placed back onto the MES initiative. Benefits were measured every 2 weeks.

Table 5-2: Time periods

Time Period	Description
1 -	Prior to 10 Mar 2014
2 -	10 Mar 2014 to 1 Jul 2014
3 -	1 Jul 2014 to 1 Oct 2014
4 -	1 Oct 2014 to 12 Dec 2014
5 -	05 Jan 2015 to 16 Jan 2015
6 -	16 Jan 2015 to 30 Jan 2015
7 -	30 Jan 2015 to 13 Feb 2015
8 -	13 Feb 2015 to 27 Feb 2015
9 -	27 Feb 2015 to 13 Mar 2015
10 -	13 Mar 2015 to 27 Mar 2015

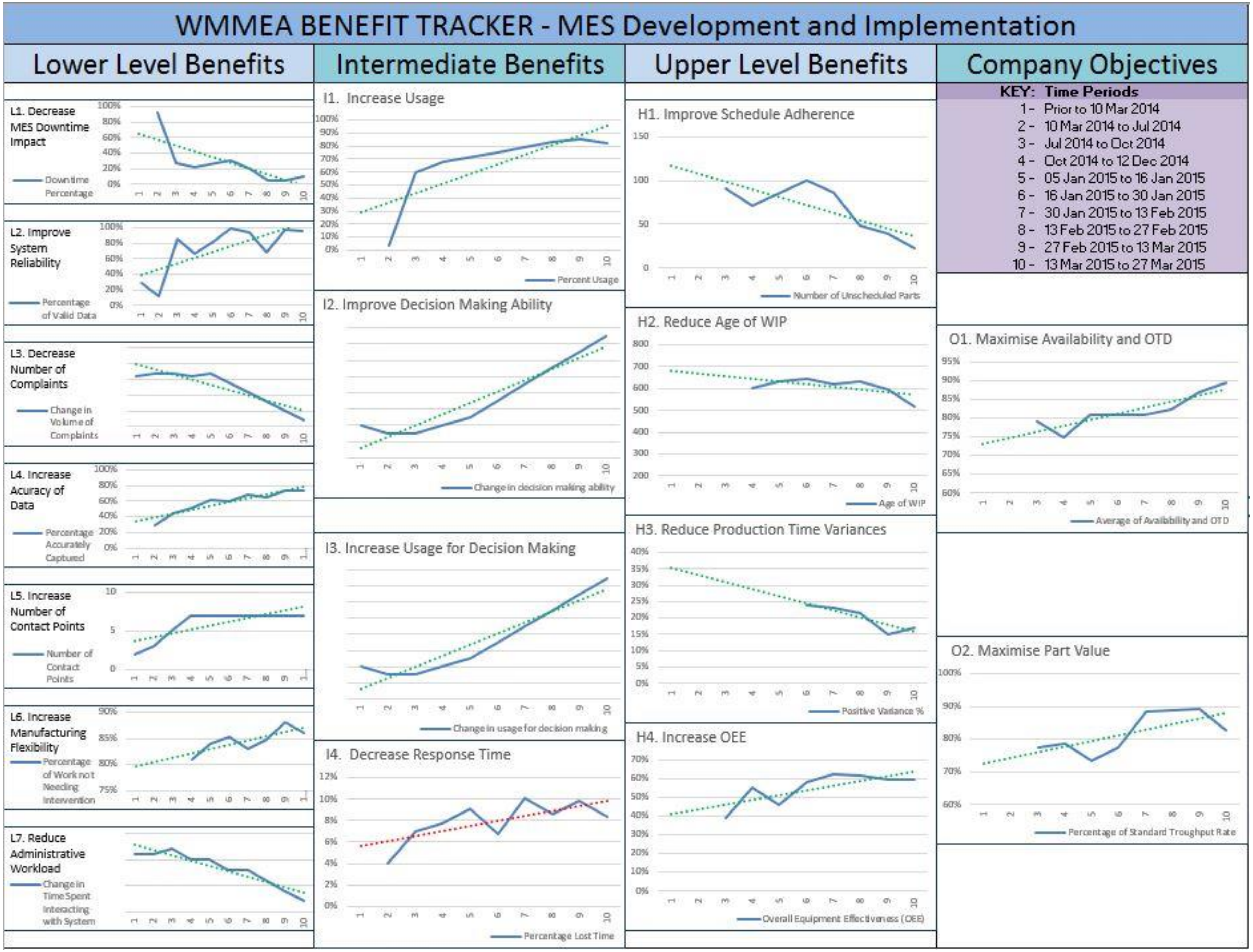


Figure 5-7: WMMEA benefit tracker.

5.2. Results – Proposition Two

The second proposition serves to verify that benefits from the implementation, as predicted by the BRM methodology, have been realised. As stated in the *"Propositions"* section, the focus is on the outcomes. These outcomes are determined from benefit measurement data. These measurements are defined on the benefits profiles and summarised on the benefit tracker template shown in the results for proposition one.

This section explains how the measurements were derived. As explained in the *"Data Gathering"* section, three methods were used for data gathering. Due to the large amount of data gathered, only one example of each method will be given in this section. A complete summary of each benefit measurement (along with data points) is available in *"APPENDIX B: Benefit Profiles*". The raw data used is available in digital format accompanying this report. The raw data is structured such that the data manipulation steps are visible. A guide to the data manipulation accompanies the data.

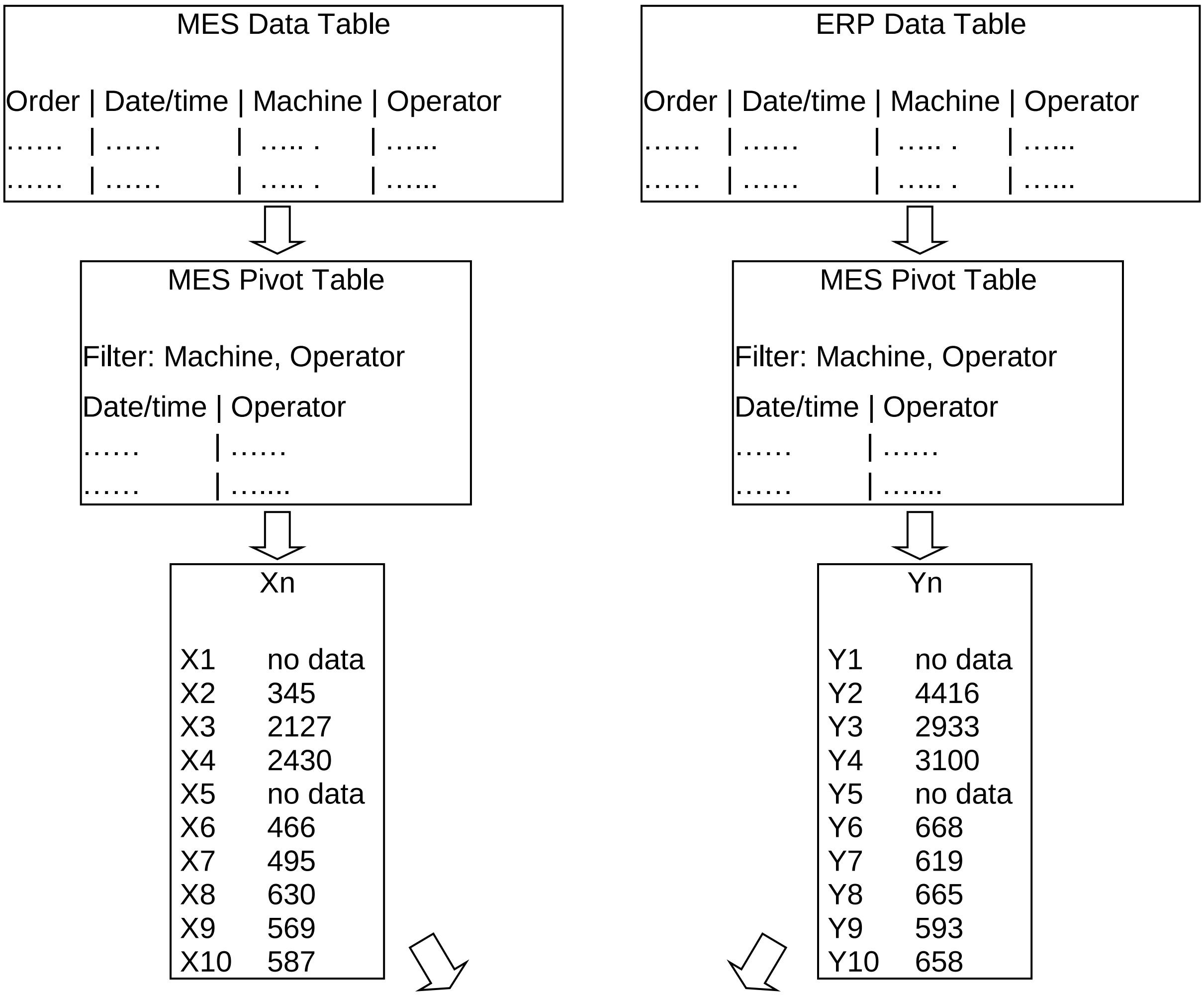
The majority of measurements (12 of 17) are made with data mined from the company's digital database. The measurement data for benefit *"L1. Decrease MES downtime impact"* will be detailed here as an example. The purpose of the measurement is described in its benefit profile and is not discussed here.

The benefit profile describes the measurement as: *"Downtime is measured as a percentage of operators who used the system per shift versus the total number of operator shifts in the given time period"*.

The data is derived and manipulated as follows (Figure 5-8 summarises the steps):

- Two SQL queries are devised. One calls historic production order data from the MES system and the other from the ERP system.

- The data in each is pivoted in order to group operator login entries by date and filter out machines not associated with the ERP system.
- For each time period “n”, the number of logins is counted. For the MES system count, call this number “Xn”. For the ERP count, “Yn”.
- Because the MRP data is reconciled weekly, no operator logins are omitted (this reconciliation is done so that operators would get paid for the days which they work). Evaluating the count of MES logins against this count gives the downtime percentage. For each period “n”, calculate the downtime percentage:
  Downtime Percentage = (1-Xn/Yn)*100
- Graph the percentage against period and insert linear trend line.
- If the trend is in the predicted direction, colour the line green, else colour it red.
- The specifics (query details, field names, formulae used, and file names) of the manipulation are found on the digital media accompanying the report.



Period	Downtime Percentage
1	#N/A
2	92%
3	27%
4	22%
5	#N/A
6	30%
7	20%
8	5%
9	4%
10	11%

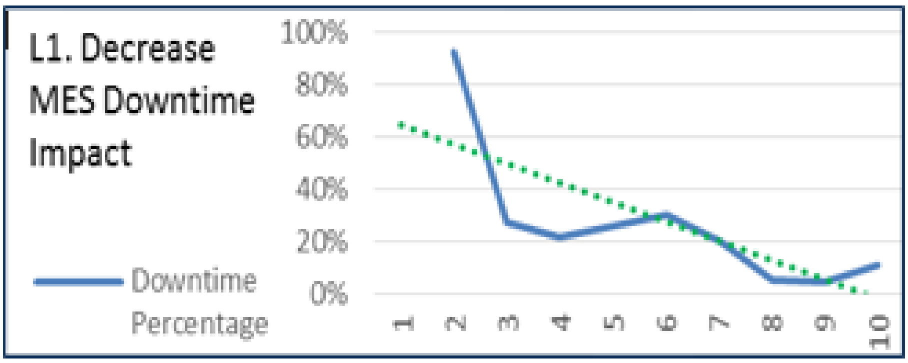


Figure 5-8: Example of data manipulation.

One measurement (*“L5. Increase number of contact points”*) was made through primary observation.

The benefit profile describes the measurement as: *“A Count of the number of contact points that management has available to interact with the system. Multiple contact points of the same kind are not counted”*.

The following contact points are observed by the researcher:

1. PC program – The interface initially supplied by the vendor.
2. Workflow PC program – A dashboard like interface, launched in December 2013, for signalling work release to logistics.
3. Status indicators – An interdepartmental dashboard, launched in March 2014, which conveys a machine status to the department which needs to address it.
4. Tablet access – July 2014 software customisation allowing access to certain modules by phone or tablet. Tablets were purchased.
5. Cell phone access – July 2014 software customisation allowing access to certain modules by phone or tablet.
6. SMS notification – November 2014 upgrade to the status indicator dashboard, allowing it to SMS status escalations to relevant people.
7. Operator terminal – A screen saver like addition to operator terminals, launched in November 2014, which displays a machine state summary to passers-by while the terminal is not in use.

Figure 5-9 shows the cumulative number of contact points across the time periods. A green trend line indicates change in the predicted direction.

Period	Number of Contact Points
1	2
2	3
3	5
4	7
5	7
6	7
7	7
8	7
9	7
10	7

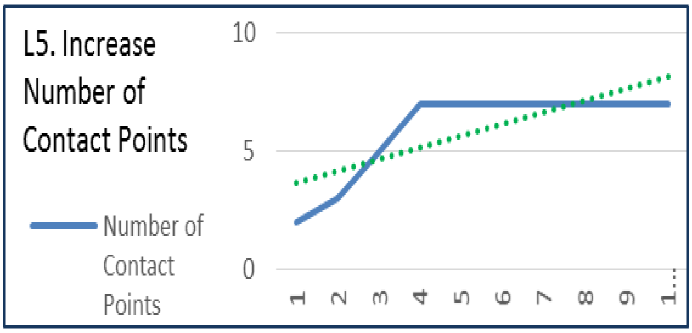


Figure 5-9: Example of data gathered through primary observation.

The third data gathering method was the structured interview. 4 of 17 benefits were measured in this manner. The measurement data for benefit *"I2. Improve decision making ability"* will be detailed here as an example.

The benefit profile describes the measurement as: *The improvement in management's decision making ability as experienced by the process engineer and the machine shop manager. These stakeholders were asked to comment on whether their ability to make decisions has increased, stayed the same, or decreased over the given time period. Each "increased" answer is given a 1, "stayed the same" is given a 0, and "decreased" is given a -1. The answers from the two stakeholders are then summed together and plotted cumulatively"*.

Figure 5-10 shows the questionnaires completed and signed by the two stakeholders. Two points need to be clarified. Firstly, the company employees refer to the MES system as CIM. This is why the word CIM is used on the questionnaire. Secondly, the title of this research report has changed since the questionnaires were completed. The old name is visible on the questionnaire.

Figure 5-11 shows the questionnaire answers summarised in a table and graphed as described in the benefit profile (green trend indicates change in the predicted direction). The following is an example of how this is done:

- The first period starts at an arbitrary point (0). This is the result of the researcher having created a quantitative scale for a qualitative measurement.
- For the second period, the stakeholders responded with *"No change"* and *"Declined"* respectively. As per the measurement definition this is converted to "0 + (-1) = -1"
- For the third period, the stakeholders responded with *"No change"* and *"No change"* respectively. As per the measurement definition this is converted to "0 + 0 = 0". Because the measurement is cumulative, the third point remains -1.
- The remaining periods are calculated by repeating the above step.

Status of Benefit: I2. Improve decision making ability.

This questionnaire serves as part of a tracking parameter for Benefit I2. As an expert in the field in question, you are requested to please answer the below question(s) to the best of your ability.

Has CIM improved your ability to make decisions in this period as compared to the previous? Your options for replies are improved, no change, and declined. Please give an answer for each time range provided.

Prior to Feb 2014:	No
Feb 2014 to Jul 2014:	No Change.
Jul 2014 to Oct 2014:	No change.
Oct 2014 to 12 Dec 2014:	No change.
05 Jan 2015 to 16 Jan 2015:	No change
16 Jan 2015 to 30 Jan 2015:	Improved.
30 Jan 2015 to 13 Feb 2015:	Improved
13 Feb 2015 to 27 Feb 2015:	Improved.
27 Feb 2015 to 13 Mar 2015:	Improved
13 Mar 2015 to 27 Mar 2015:	Improved.

Consent:

I, Jaco van Niekerk, give my permission to have the above information published in the research report titled "Development and Implementation of Computer Integrated Manufacturing (CIM) using Benefits Realisation Management (BRM) methodology". I further acknowledge that:

- I understand that the report is to be submitted, by Jovan Jevtic, to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Science in Engineering.
- I am familiar and comfortable with the topic of the report.
- I have read the benefit description and understand the context behind the question(s).
- I understand that this information is not confidential or anonymous.
- To the best of my ability, I have provided honest and accurate answers to the question(s).

Signed: [signature] CIT facilitator

Date: 14/04/2015

Status of Benefit: I2. Improve decision making ability.

This questionnaire serves as part of a tracking parameter for Benefit I2. As an expert in the field in question, you are requested to please answer the below question(s) to the best of your ability.

Has CIM improved your ability to make decisions in this period as compared to the previous? Your options for replies are improved, no change, and declined. Please give an answer for each time range provided.

Prior to Feb 2014:	
Feb 2014 to Jul 2014:	DECLINED
Jul 2014 to Oct 2014:	NO CHANGE
Oct 2014 to 12 Dec 2014:	IMPROVED
05 Jan 2015 to 16 Jan 2015:	IMPROVED
16 Jan 2015 to 30 Jan 2015:	IMPROVED
30 Jan 2015 to 13 Feb 2015:	IMPROVED
13 Feb 2015 to 27 Feb 2015:	IMPROVED
27 Feb 2015 to 13 Mar 2015:	IMPROVED
13 Mar 2015 to 27 Mar 2015:	IMPROVED

Consent:

I, NEELS DE WET, give my permission to have the above information published in the research report titled "Development and Implementation of Computer Integrated Manufacturing (CIM) using Benefits Realisation Management (BRM) methodology". I further acknowledge that:

- I understand that the report is to be submitted, by Jovan Jevtic, to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Science in Engineering.
- I am familiar and comfortable with the topic of the report.
- I have read the benefit description and understand the context behind the question(s).
- I understand that this information is not confidential or anonymous.
- To the best of my ability, I have provided honest and accurate answers to the question(s).

Signed: [signature]

Date: 15/04/2015.

Figure 5-10: Questionnaire example.

Date	Change in decision making ability
1	0
2	-1
3	-1
4	0
5	1
6	3
7	5
8	7
9	9
10	11

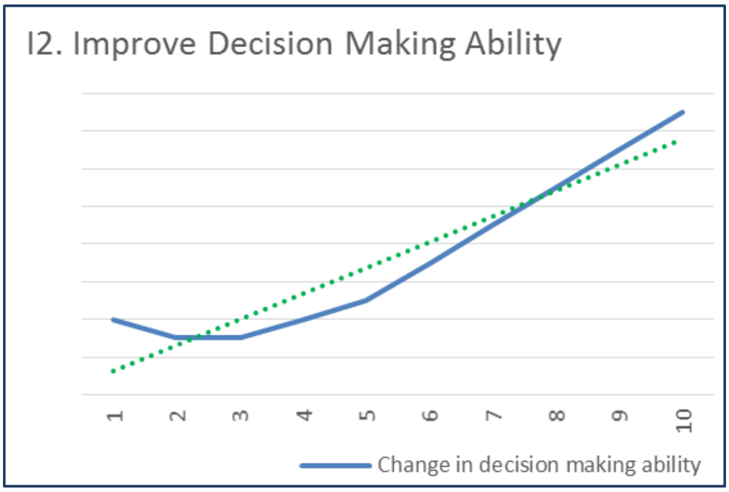


Figure 5-11: Example of data gathered through structured interview.

In summary, this chapter has detailed the case, initially defined in the *“Introduction”* chapter. In the results for proposition one, the reader is taken through the deliverables of the applied BRM methodology. This includes the strategy map which was used to initially find a place for the MES system in the company. The benefits dependency map then summarises the issues and benefits uncovered in the stakeholder workshops. Appendix A and B contain the details of this summary. While these details are not crucial for satisfying the proposition, they give the reader an understanding for the issues the stakeholders had to deal with and the benefits that they wanted to achieve. The solution management template summarises the projects that the stakeholders devised in order to address the issues and realise the benefits they wanted. Appendix C details the outcomes of these projects. Finally, the benefit tracking template gives the reader a feel for the sort of feedback that stakeholders had throughout the implementation. The second proposition is concerned with the measurement outcomes for each benefit. Since these were summarised in proposition one, the results for proposition two go into more detail on how the measurements were derived.

6. DISCUSSION

This chapter is a critique of the BRM methodology and of the results obtained in this research. It serves as a platform for the researcher to put the results into context by relying on knowledge gained through ongoing participation in the company's activities. Opinions which the researcher cannot verify, but feels should be considered, are highlighted.

This chapter begins with a discussion on BRM methodology. Here the adaptation of the method and the reasons behind why the approach is taken are revisited. The details of the initiative are then evaluated against the requirements of proposition one. The aim is to see whether the approach taken by the company was as specified by BRM. The outcomes of the approach are the benefits realised, which are measured quantitatively. These measurements are evaluated against proposition two. Finally, the reliability and validity of the approach taken by this research report are tested.

6.1. Discussion on BRM Methodology

It is important that the reader does not confuse the established research methodology applied in this report (single case study evaluation) with the BRM methodology under examination. This report is the first documented attempt at applying BRM methodology for MES system development and implementation. The *"Literature Review"* chapter identifies a case where Business Process Re-engineering (BPR) is used for a similar purpose. While this process has many similarities with BRM, sufficient differences are identified to call this case study unique.

BRM methodology is selected due to its stated applicability in large scale IT system implementations. In particular it is able to specify system requirements from a company objective (rather than a supplier module) perspective; and it is able to align stakeholders to these requirements. This presents an organisation centred approach to implementation which the *“Literature Review”* chapter has identified as an important gap in MES system implementations.

Although this report specifies BRM methodology, some adaptations had to be made by the researcher in order to streamline the broad body of BRM knowledge into a, MES specific, step like methodology which can be applied in companies that do not have a BRM program. The methodology is able to derive:

- The business requirements (or benefits) from MES systems.
- The hurdles (or issues) to implementing MES systems.
- The business changes and systems that need to be put in place to overcome the issues and realise the benefits.

The outcomes (identified necessary for MES development and implementation) of the adapted methodology are:

- A strategy map.
- Stakeholder management methodology.
- A benefits (dependency) map.
- Benefit profiles.
- A solution management template.
- A benefits tracking template.

The following are some key adaptations made and the reasoning behind them (The full details are available in the *“Theoretical Framework”* chapter):

- Stakeholders and the required interaction between these stakeholders has been predefined. This eliminates the need to dive into BRM theory which details stakeholder selection and management.
- An “issues” section replaces the traditional BRM “systems” section. BRM is usually used to implement existing systems (these would fall under the traditional “systems” section). MES however implements highly customised systems and the “issues” section

helps to specify their requirements by highlighting which issues they need to address.

- The traditional BRM “systems” and “business changes” sections have been batched into one “enablers” section. This encourages projects to be specified which concurrently address system implementations as well as the process changes which need to accompany them.

The adapted methodology has no company specific or environment specific references. Any references to teams and stakeholders could be considered applicable in numerous companies.

6.2. Discussion on Proposition One

This section refers to the initiative specific results of applying the adapted BRM methodology at WMMEA. Application of the BRM methodology is an extensive exercise that derives the company specific requirements for MES systems development and implementation; and then measures the benefits gained from these systems. The measurement of benefits is not done only to gauge success, but also to identify and remedy shortfalls in the implementation.

The results related to this proposition aim to tell the reader a “story” about the events that took place during the implementation. To satisfy the proposition, results do not have to be presented through this “story” approach. This is done to expose the reader to events he may otherwise not have been able to anticipate. While the researcher recognises that these events cannot be generalised to all companies, he believes that detailing them will be of value to most readers planning to embark on a similar initiative. This belief is backed by observing that both Meyer et al. [3] and Scholten [7] identify organisational issues (Table 6-1) common with those identified in this case study. Neither of these texts however give “real world” examples of how these issues occurred or how they were handled.

Table 6-1: Common organisational issues

This case study	Meyer [3]	Scholten [7]
System Misalignment		1. Excessive reliance on excel [Location 329]. 2. Failure to follow ISA95 [Location 1570].
Operator Buy-in	Cognitive problems [p174].	Implementation guidance [Location 1039].
Software Interface		
Low Quality Data Fed Into the System		
Single Point of Control	Central and consistent database [p8].	
Incomplete Functionality		Customisation requirement [Location 837].
Roles and Responsibilities		No best practice available [Location 1172].
Backup System		

The first proposition requires the report to show that it was possible to apply the adapted methodology for the development and implementation of MES at WMMEA. This report shows that the proposition is satisfied as follows:

- Each of the deliverable specified by the adapted methodology have been created and are available in the *"Results"* chapter.
- The first deliverable of the BRM methodology is to identify which company objectives MES will address and then identify how implementation of this system will fit in with the many programmes running concurrently. This is why BRM is often considered a branch of programme management. The following relationships were identified:
  - The company objectives that MES aims to address at WMMEA are an increase in part value and an improved OTD to customer. From this very point, it is understood that any decisions made regarding the MES system must be aimed at eventually leading to one of these.

    - These objectives are further influenced by the machine shop productivity programme and the Sales and Operations Planning (S&OP) programme running concurrently to the MES implementation. The weighted impact of the various programmes on the downstream objectives was estimated during the BRM workshops, but their ultimate contribution to the benefit measurements could not be identified. This is discussed further in the *"Validity and Reliability"* section that follows.

- Stakeholders (referred to as benefit owners in BRM methodology) participated as per the guideline set out in the adapted methodology. They were made accountable for realisation of benefits in their area of influence and were responsible for instating the enablers that led to these benefits.

- The second deliverable of the adapted BRM methodology is the benefits map. This is the key working document, used in workshops to specify the enablers (projects) that must be instated and to identify the causal links between these and the company objectives.

- There are no broken causal links in the benefits map (I.e. it was possible to predict all the relationships between the enablers to be instated and the company objectives to be achieved). This shows that the adapted methodology is able to specify a complete set of requirements for the MES system at WMMEA.

- The requirements specified for the system and their timing are detailed in the *"Solution Management"* section; the third deliverable of the adapted BRM methodology (details of project execution are out of the scope of this report). The key requirements (specific to WMMEA) were identified as follows:
    - System alignment: Four systems were involved in shop floor control. Of these, the MES and the Kanban systems handled similar data interchangeably. Without either of the systems having the full data set, neither could accurately account for

the state of production at any one time. The Kanban system was removed and MES was hard linked to the ERP.

- Operator buy in: Operator performance measurements were removed and operators were involved in the project to simplify and redesign the MES interfaces.
- Software interface: input requirements were reduced from 10-20 fields down to a maximum of 3.
- Quality of data fed into the system: MES functionality was adapted to handle actual versus planned scenarios. This in turn helped gather, group, and correct data inaccuracies.
- Single point of control: MES was made the chief source of data for all production monitoring. The data was then structured into specific formats for specific areas of business.
- Increased functionality: Both hardware and software functionality. Primarily, capturing had to be in real time to allow for fast response from supporting departments.
- Roles and responsibilities: Expertise in all system maintenance and execution tasks had to be developed in-house. This included the ability to cross train.
- Backup systems: Networked electrical systems are susceptible to power outages and network unavailability. System restoration and catch-up had to be made quick and easy.

- Each benefit was measured (tracked) and is summarised into a benefit profile. Benefit profiles serve to give a common understanding of each benefit amongst the stakeholders. They are compiled alongside the benefits map.

- Measurement data is summarised on the benefit tracking template, the final required deliverable of the adapted BRM methodology. This template is used for visual management of the implementation. Benefits of solution management can be tracked and unexpected results can be identified and addresses.

- Measurement data was mined directly from the company's main database and then manipulated to the measurement's requirement. Only when data was not available in the company's database, was it gathered through direct observation or structured interview. It is necessary that all data be quantitative so that trends could be identified in the benefit measurements.

- 5-10 data points were captured for each measurement. It is possible to derive a linear trend for each.

6.3. Discussion on Proposition Two

The second proposition focused on the outcomes of the MES system implementation. As discussed in the *"Literature Review"* chapter, a key strength of the BRM method is its ability to link an enabler (such as a process or system change) to a number of high level company objectives through, sometimes unintuitive, cause and effect relationships. Identifying these relationships is key to understanding the mechanics behind how a system behaves within a company. This in turn helps to remove doubt and bias from the development of business cases. MES system implementation is tracked through measurement of the benefits it is predicted to create at various levels in the company. It is required that a benefit be defined as a measurable parameter. This way, the change in the benefit is the benefit gained. A few points on interpreting benefit measurements in this case study:

- There are no targets for the magnitude of the benefit gained because no benchmark could be identified in the setting out of this research report. For the purpose of this report therefore, a benefit change in the desired direction, regardless of magnitude, is considered a positive gain for the company.
    - The benefits gained could become a benchmark if the initiative is to be repeated.

- Some measurements have no values on the vertical axis. Due to the method of data collection only a direction of change and a relative rate is identified (sufficient to satisfy the second proposition). The detail of each measurement is defined in the relevant benefit profile.

The second proposition requires the report to show that changes in the benefit measures happen in the predicted (desired) manner. Observing measurement data, this report shows that the proposition is satisfied as follows:

- It is possible to ascertain a trend for all fifteen benefits and both company objectives.
  - Benefit measures all have between 5 and 10 data points.
- 14 of 15 measurements have a trend in the predicted direction.
  - The exception (highlighted in Figure 6-1) is benefit *"I4. Decrease Response Time"*. It shows that the time it takes supporting departments to respond to downtime events has increased.
    - This is against expectation as this benefit leads from the following lower level benefits and enablers:
      - Project 7 – Roles and responsibilities for addressing downtimes have been defined.
      - Project 6 – System functionality for signalling downtime causes has been improved.
      - Benefit L5 – The number of contact points that supporting departments have to interact with the system has increased.
      - Benefit L6 – The ability of the system to handle unplanned work has improved.
    - All the causes that are predicted to have an impact on this benefit are trending in the desired direction. This

typically indicates that there may be a factor that has been overlooked.

- To add to the above reason for why this measurement is unexpected, the resulting benefit *"H4. Increase Machine Shop OEE"* can be noted. It trends in the desired direction even though its causal benefit *"I4"* does not.
- The following is the <u>researcher's unproven opinion</u>. The benefit measure, not the benefit itself, may have been influenced negatively by benefit *"L4. Increase Accuracy of Data"*. To explain practically:
    - Operators have been empowered to capture what happens on the floor in far more detail than they previously could (it was previously only practical to report downtimes with major impact).
    - Short, yet regular, downtimes would previously go unreported. The time lost would be bundled into the run time of the operation (a speed loss).

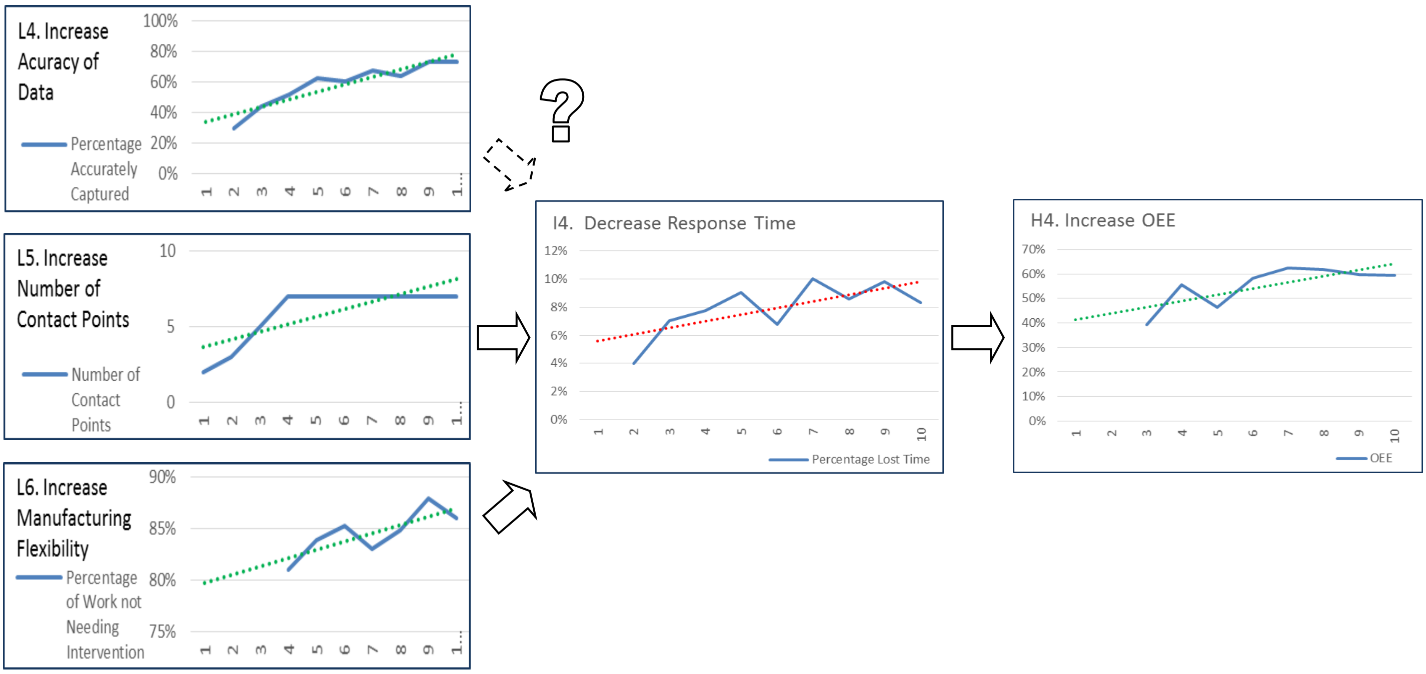


Figure 6-1: Unforeseen measurement.

- There are too many benefits and relationships to discuss individually. They are summarised in the benefits map and discussed individually in their benefit profiles available in *“APPENDIX B: Benefit Profiles”*. A few of the benefit relationships which drew the most attention should however be mentioned:
    - Intermediate benefit *“I1. Increasing system usage”* was a focal point of 4 enablers and 3 lower-level benefits. There was a sense that (whether or not the system worked well) reaching a “critical number” of machine shop operators using the system would ensure company-wide focus and buy-in for the initiative. Figure 6-2 shows that this was achieved as early as period 3.
        - To do this, one of the most demanding enablers had to be instated early on. *“Project 1 – System alignment”*, was achieved through the removal of the well-entrenched Kanban system.
        - The direct, lower-level, benefit gained from instating this enabler was benefit *“L2. Improve system reliability”*. This benefit reached its peak as early as period 3.
            - Two drops in this benefit can be noted in periods 4 and 8. The researcher suggests that these are attributed to the introduction of new machines into the MES system which required the clean out of obsolete data.
        - Increased usage however took some time to filter forward into its resulting benefit *“H1. Improve schedule adherence”*. <u>The researcher suggests</u> that this was the fault of the strike action which took place in period 3 (detailed in the *“Uncontrollable Events”* section of chapter 1). It is the researcher’s unproven impression that this event created unrealistic, and

badly managed, demands on the production schedule.

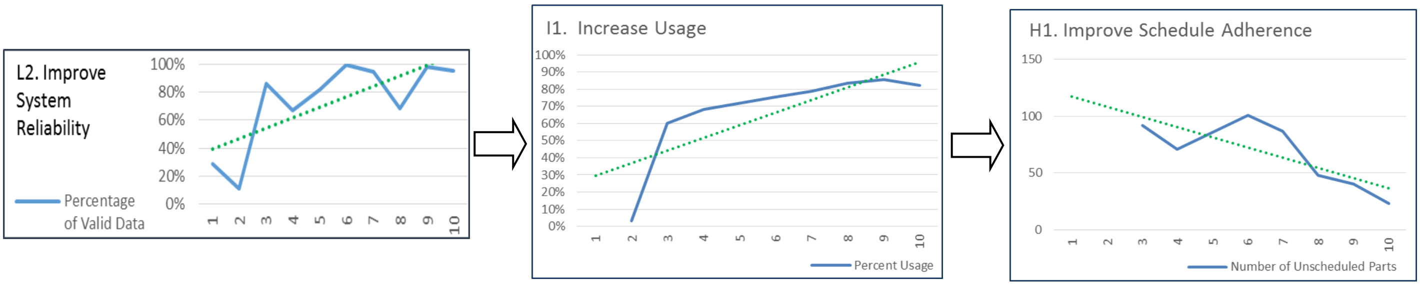


Figure 6-2: Early win.

- The benefits which created the most excitement amongst stakeholders (as perceived by the researcher) were intermediate benefits *"I2. Improve Decision Making Ability"* and *"I3. Increase Usage for Decision Making"*. These (Figure 6-3) suggested that management will be able to make better decisions regarding machine shop operations with the assistance of the MES system.
  - These required that lower-level benefits *"L4. Increase Accuracy of Data"* And *"L5. Increase Number of Contact Points"* be realised. *"L5"* peaked in period 4 while *"L4"* gradually improved across the measured periods. The relationship between these and the intermediate benefits appears to be closely correlated with change in both decision making ability and usage for decision making "accelerating" from period 4.
  - As a predicted knock on result of realising benefits *"I2"* and *"I3"*, management was able to implement programs which narrowed down the sources of production variances and tackle them systematically. This led to an improvement in higher-level benefit *"H3. Decrease Production Time Variances"*.

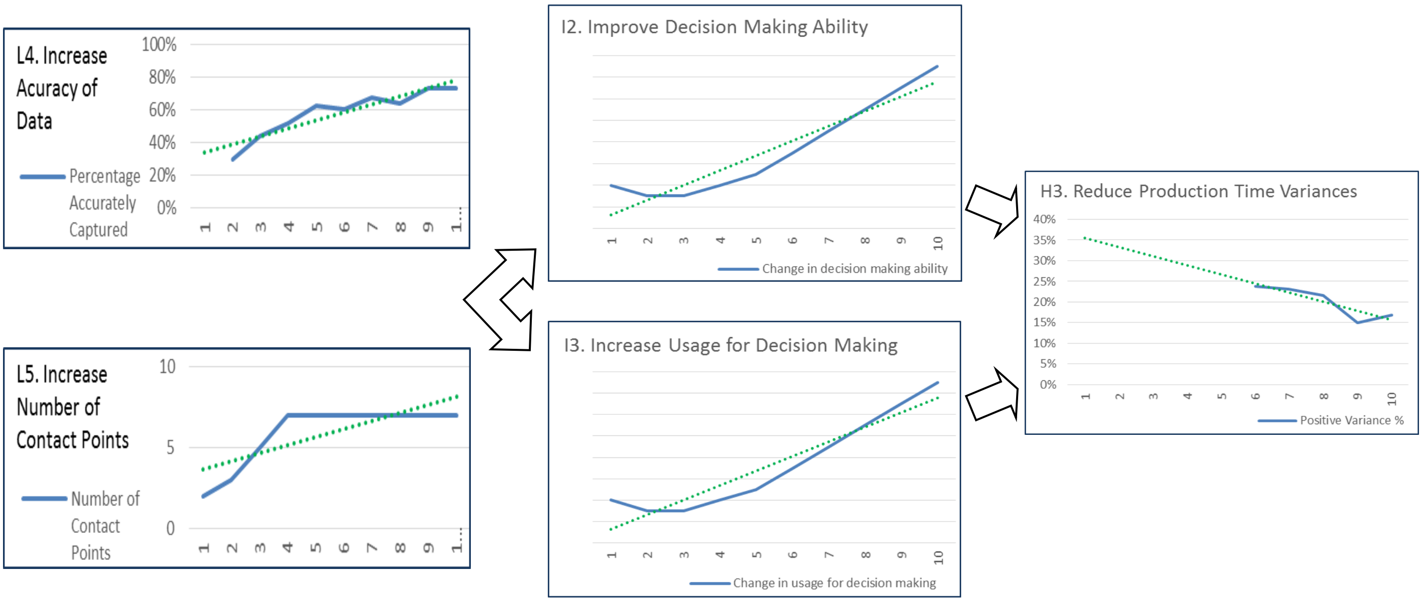


Figure 6-3: "Exciting" benefits.

- Higher-level benefits generally trail after lower-level benefits. Figure 6-4 shows the benefit chains that lead to objective *"O1. Maximise availability and OTD"*.
  - The greatest improvement in objective *"O1"* happens in the last two periods.
  - *"O1"* is dependent on higher-level benefits *"H1"* and *"H2"* which similarly show improvement in the later periods (periods 7 to 10 and 8 to 10 respectively).
  - Intermediate benefits fittingly show improvement in the intermediate periods. *"I1"* from period 2 onwards and *"I2"* and *"I3"* from period 4 onwards.
  - Lower-level benefits *"L1"* and *"L2"* peak as early as period 3. *"L5"* peaks in period 4. They remain stagnant from there on.
    - Lower-level benefit *"L4"* similarly shows a sharp improvement up to period 5, but then continues improving steadily over the later periods. This behaviour falls in line with its unique dependence on intermediate benefit *"I1"*, which improves consistently over time.

- The causal relationships are not always as evident as the ones described in the previous points. Lower-level benefit *"L3. Decrease the Number of Complaints"* is a clear exception. The researcher wishes to note that exact mathematical relationships between measurements are not known and so interpretations are speculative. To this point, the researcher speculates that the number of complaints (*"L3"*) can be expected to increase as system usage (*"I1"*) increases. Only once usage begins to peaks, can it be expected that addressing complaints will cause their number to decrease.

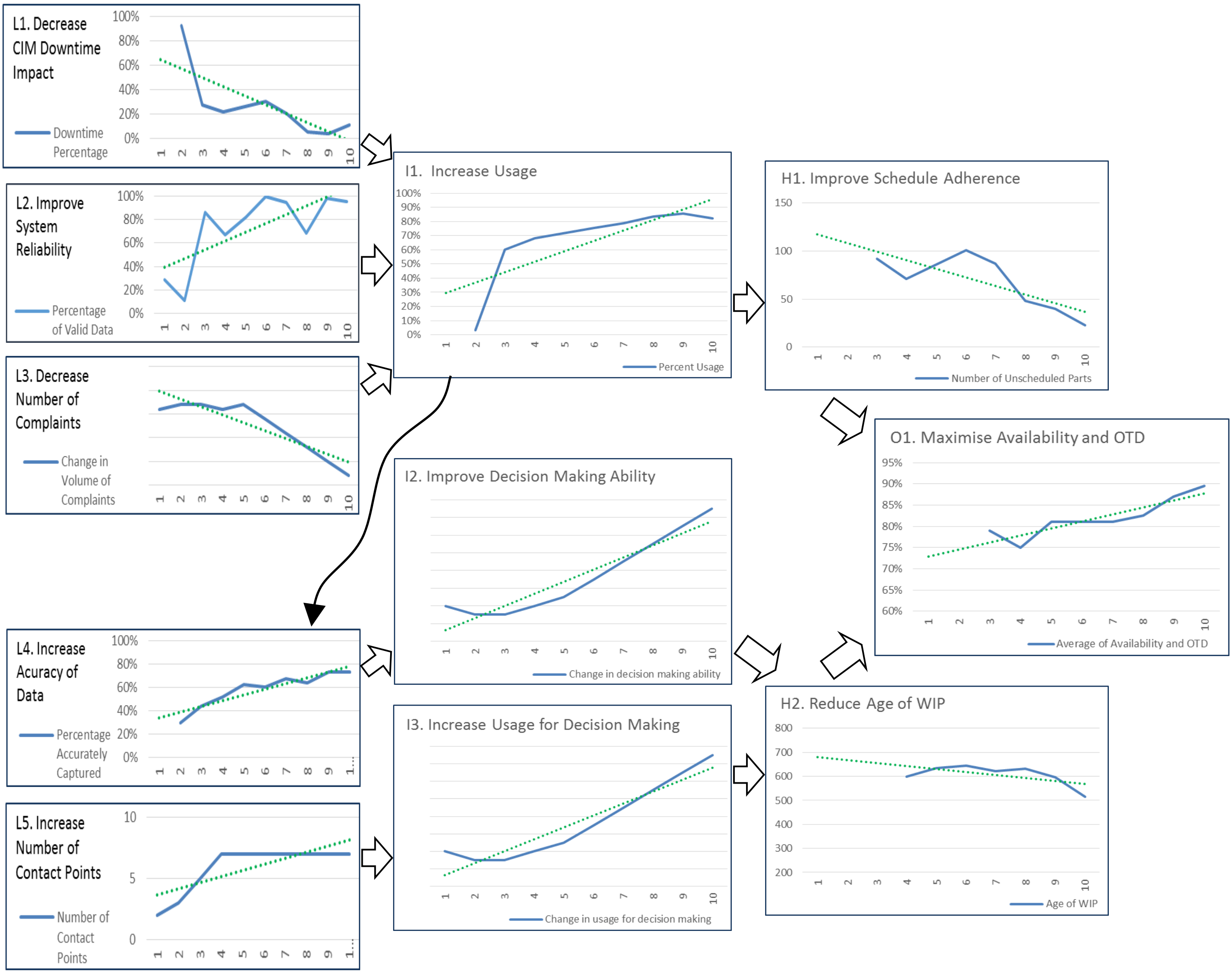


Figure 6-4: Benefit chains of company objective *"O1"*.

- Both measurements of the company objectives (shown in Figure 6-5) trend in the predicted (desired) direction.
    - This means that the company is performing better than it did at the start of the project.
    - The impact from supporting initiatives on the company objectives is unknown. These are discussed further in the *"Validity and Reliability"* section.

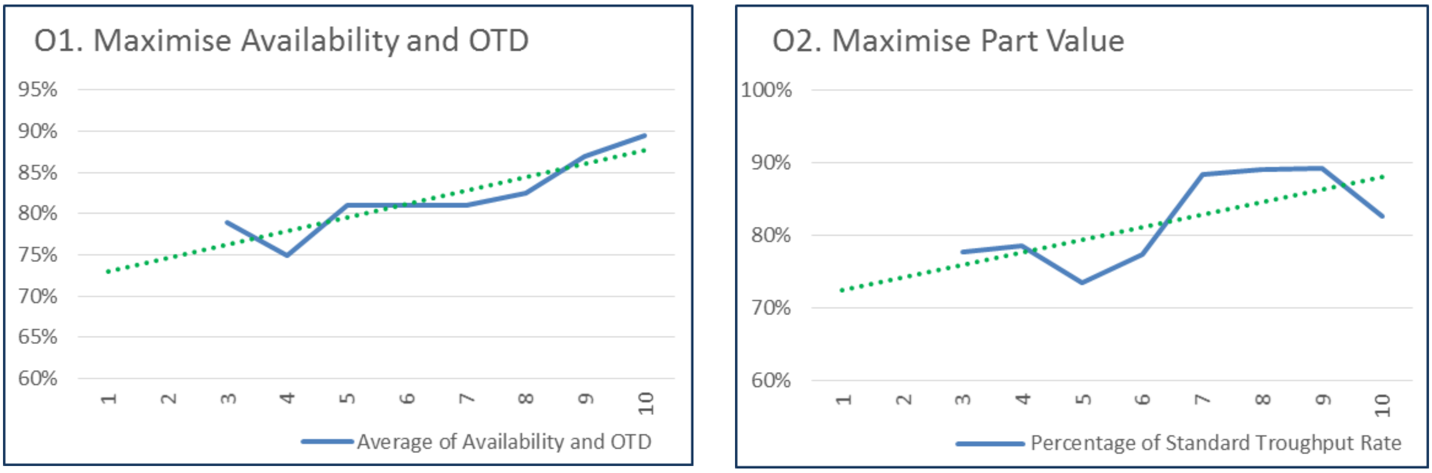


Figure 6-5: Trend in company objectives.

6.4. Validity and Reliability

This section is separated from the rest of the discussion because the researcher wants the reader to dedicate his focus to the results of the study. Adding comments to validate the method in between points in the discussion would repeatedly bounce the reader between considering the topic of research and the research approach. However, in order to demonstrate that the approach taken is both methodologically sound and sufficiently rigorous; the following four tests are discussed:

6.4.1. Construct Validity

Cases are often complex and take place in uncontrolled environments. This may give a researcher various avenues for collecting data and specifying measurements for addressing a research question. This creates opportunity for the researcher to specify poor measurements and use subjective judgement in collecting data.

In this case, all measurements were agreed on with stakeholders in the system. This is a form of participant validation which Yin [30] recommends. Furthermore, the company objectives that the system addresses are not new measurements specified for the case. They are established business metrics.

Data collected is quantitative. It was collected from the main company database and the values are not subjected to interpretation. The direction of trends is therefore also not open to interpretation.

All points made by the researcher, which are unsupported by the evidence, are highlighted as the researcher’s opinion.

6.4.2. Internal Validity

Because this case study is an evaluation, internal validity is particularly important. I.e. it doesn't present information to be pondered or interpreted by the reader, it presents a quantitative conclusion (in the form of trend data). Internal validity is the need to prove that the trends and relationships obtained, are not a matter of coincidence or due to aspects not considered by the researcher. In case study research, it is often the case that it is not possible to collect sufficient data to determine statistical validity. This case study suffers from the same problem. There are however alternative techniques, used in case study research, to determine internal validity. Three analytical techniques are applied to validate the results.

<u>Pattern matching</u> evaluates the measurements derived in the case study to those predicted at the start of the study. This is a particularly good technique to use for validating BRM methodology, because BRM methodology relies heavily on predicting the benefits of initiatives base on predicting cause and effect relationships at play within the company. 14 of 15 benefits were predicted correctly. In the discussion, the researcher suggests that this benefit is predicted correctly but that the measurement method is flawed.

In pattern matching, it is important to consider that no major underlying variable (for example: a swing in the market conditions) is responsible for a general shift in all measurements (a rival theory). In this case it is important to note that the external conditions affecting lower level benefits are different to those affecting high level company objectives. It is therefore unlikely that a single variable will create this sort of effect. I.e. Low level benefits are affected by fewer things that generally happen on the shop floor, while high level objectives are affected by more factors, some of which may be far outside the company. Some factors however do need to be considered and these are discussed in the following two paragraphs.

Chronological sequence time series analysis matches data points with the events taking place at the time the data point is taken. Because case studies are usually not done under controlled conditions, fluctuations in the measurement data can often be explained by considering major events that took place during data collection. The data captured in this research is separated into periods. Each period presents different considerations to the case (e.g. a period in which there was strike action) and the effect of these considerations is visible in the trend data.

The logic model aims at unearthing cause and effect relationships. Like pattern matching, it too relies on predicting the relationship between data. Unlike pattern matching however, it spans across measurements. It identifies causal links between measurements which may be based on different data. In this report, the method is used to validate the relationship between benefits at different levels. It may for example be posed that while pattern matching validates the majority of the predicted benefits, a certain high level benefit may have conveniently been a result of an unexplained external effect. The BRM model has predicted that a benefit will be obtained, as an effect of actions taken by the project teams. These actions were taken and pattern matching showed that the benefit was obtained. In the discussion the researcher further shows that benefits occur at logical points in time. I.e. A higher level, knock on, benefit only occurs after a lower level benefit has occurred. If the opposite had been the case, the report would have had to conclude that the prediction was invalid. Unfortunately, this effect is not clear between all benefits. The researcher suggests that complex relationships are at play and provides scenarios that potentially lead to the observed effects. Analysing the data from this (second) perspective is a form of triangulation of findings. I.e. coming up with the same result when looking at the case from a different perspective.

6.4.3. External Validity

A good case study presents conclusions, methods, or explanations which are of interest or importance to others. This report aims at presenting a methodology that will improve MES system development and implementation. The report recognises that the findings presented cannot be generalised across all industries. It further recognises that the method presented is not compared to potential alternative methods. A case study is however generalizable to its theoretical propositions. In this case, it can be said that the findings are valid for any MES implementation WMMEA chooses to undertake in the future or in another branch. All WMMEA branches undertake the same activities using the same business model. It can further be said that the same is valid in manufacturing throughout the WEIR group which shares its resources and management practices. This is the group that may find this research of importance.

The researcher however hopes that attempts will be made to extrapolate the findings further. The adaptation to BRM methodology was made in order to accommodate MES systems. No company specific adaptations were made. There is therefore potential for companies in similar industries (i.e. small lot manufacturing) to attempt the method. As the nature of the industry changes, the likelihood of applicability will decrease.

6.4.4. Reliability

Reliability considerations exist to reduce error and bias in a case study research. There are two focus areas.

<u>Case study protocol</u> needs to be based on established (validated) methodology. This is detailed in the research methodology (establishing propositions, bounding the case, etc.). The methodology applied in this report is case study research for evaluation, as described by Yin [30]. The case study specific protocol also needs to be documented in detail. Sufficient detail implies that a later researcher will be able to follow the same protocol and repeat the study. The specific methodology applied in

this case study is the adapted BRM methodology. Considering that BRM methodology is a body of knowledge too large to be detailed in this report, the researcher summarises the main points and references the further reading necessary to obtain a working knowledge of the methodology. The adaptations made to the methodology are explained in detail in the *"Theoretical Framework"* chapter. The reasoning behind these adaptations is discussed both in the *"Theoretical Framework"* and *"Results"* chapters.

The researcher needs to maintain a case study database. This is a record of all the data (or evidence) he's obtained throughout the research. A reader, should he choose, should be able to separate out and evaluate the raw data used in the report. He can in this way, validate that the researcher's manipulation of data is unbiased. While the above protocol dictates how data is to be gathered, this database should go into more detail about the exact source of data.

This report contains a few forms of data. All the information detailing the activities that took place (the data used to satisfy the first proposition) is presented in the *"Results"* chapter of this report. For proposition two, only a summary of the measurement data is presented in this report. In the form of graphs, in the *"Results"* chapter; and as tabulated data (the value of the graphed data points) in Appendix B. The raw data, which is manipulated to get these results, is too large to fit into the report. This data accompanies the report in digital format. The data extracted is clearly labelled, however the queries used to extract it are not detailed. The code behind these queries may be confidential, but it is also likely to be of no use to anyone without a map of the company data structure. The queries used are identified by name. It is a company requirement to store the detail of these named queries indefinitely in a secure location on tape. It is therefore always possible to retrieve this information if necessary. Because the data manipulation is done computationally (using excel formulas, pivot tables, etc.), the digital format of the data is, as far as possible, structured to demonstrate the manipulation process. Where this is not clear, instructions for computational manipulation of the raw data are presented alongside the data. A final two points should be mentioned. 1 of the 17 measurements was made by direct observation (a count by the researcher) and can only be validate by repeated direct observation on site. 4 of the 17 measurements were made through structured questionnaires. Copies of these signed questionnaires are available in digital format as part of the accompanying data.

6.4.5. Limitations of the Research

The following are some limitations that the researcher was unable to overcome:

- Unknown data accuracy – Due to the volume of data and time over which it was captured, the researcher is unable to audit individual data points for accuracy. The requirement for accuracy is satisfied by recognising that it is only necessary to identify a trend (increase or decrease). All changes in measurement data exceeded 4%. Considering that company master data is used (the same data used for financial reporting) and that this data comes from an audited ERP; the researcher has chosen to assume that any potential data inaccuracy could not be significant enough to alter the results of the research.
- No experimental control and external influences – Ideally the researcher would have cordoned off a number of machines on which to not implement MES. These would serve as a control against which to gauge the machines using MES. This action is however not in the interest of the company under consideration. This control would have been a great boost to validity as it would have been able to isolate the effects of the unknown factors that influenced the measurements. For example: It was known that objective O2 would be influenced by the machine shop productivity programme. The result of this influence could have been measured on the control and factored out of the measurement data.

- Statistical validation – Statistical validity adds to internal validity. In this report, measurement sample sizes are limited and distributions are unknown. This makes determining statistical validity impossible.
- Lack of direction – There is no set measure for determining how many benefits have to be achieved, out of the total predicted, in order to say that the adapted methodology is valid. The researcher is fortunate that a large majority (16 out of 17) are achieved; and that he is able to present a plausible explanation for why the remaining one is not. The researcher is also unable to identify a reliable benchmark for the magnitude of the benefit to be achieved.
- Unknown cause and effect relationship – Relationships between benefits were predictions made by the stakeholders. No mathematical relationship can be attributed to these. While an observed relationship "seems" causal, the causality cannot be confirmed in all situations. For example: It was predicted that addressing operator complaints will increase system usage. The effect of increased usage by operators can however lead to more complaints. The lower-level measurement for complaints may then seem stagnant while usage increases. When using visual inspection, as is done in this report, this effect will mask the causal link between the two.

7. CONCLUSIONS

This research report investigated the question *"Is BRM a valid method for MES development and implementation?"* through a case study conducted at WMMEA.

It is understood that due to the limitations of single case study research, it is not possible to answer this question in a generalised manner. It is however possible to generalise the case to the theoretical propositions posed.

Two theoretical propositions have been posed:

The first proposition required the report to show that it was possible to apply the adapted methodology for the development and implementation of MES at WMMEA; and to show that the methodology was applied. The proposition is shown to be true with all the deliverable specified by the adapted methodology being derived. These deliverables include:

- A company specific strategy map shows that the objectives to be achieved are an increase in part value and an improved OTD to customer.
- A company specific benefits map details the cause and effect relationships between all the benefits that need to be realised in order to achieve the company objectives. Having no broken causal links in the benefits map shows that <u>the adapted methodology is able to specify a complete set of requirements for the MES system at WMMEA.</u>
- The specification of requirements was followed by projects executed to achieve them. Requirements were specified as:
    - System alignment.
    - Creating operator buy-in.
    - Software interface improvement.
    - Improved quality of data fed into the system.

- Creation of a single source of data for shop floor management.
- Increased hardware and software functionality.
- Defining of roles and responsibilities.
- Development of a backup system.

The second proposition required the report to show that changes in the benefit measures happened in the predicted (desired) manner. Measurement data shows that this proposition is satisfied as follows:

- It is possible to ascertain a trend for all fifteen benefits and both company objectives.
- The majority of benefit measurements (14 of 15) have a trend in the predicted direction.
- Higher-level benefits generally trail after lower-level benefits.
- Both measurements of the company objectives trend in the predicted direction.

These results pass the test for reliability and the three tests for validity. The limitations are found to be insufficient to invalidate the results.

Based on the acceptance of the propositions and tests of validity and reliability, it can be concluded that: In the case of WMMEA *"BRM is a valid method for MES development and implementation"*.

8. RECOMMENDATIONS FOR FUTURE WORK

This report provides evidence that BRM is a valid method for MES development and implementation at WMMEA. The researcher hopes it will motivate further research in the fields of BRM and MES. The researcher has considered the following potential research topics:

- Answering the same question on a generalised (not specific to any one company) scale. The work requirement to gain a statistically valid sample number may however be limiting. Additionally, there may be little industrial requirement for validating the method statistically.

- The methodology developed here could be used to identify critical success factors for the implementation of MES in companies. This would be done by collating the following from a significant number of companies:
    - The most common company objectives that MES aims to achieve.
    - The most common issues that MES aims to address.
    - The likely enablers that a company will have to instate in order to address the issues and achieve the objectives.

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APPENDIX A: Issue Themes (Root Causes)

System Misalignment

The perceived symptoms for this issue theme (as they were described in the workshops) are summarised in Table A-1.

Table A-1: System misalignment symptoms

Multiple Systems: Three separate systems, auxiliary to the ERP, are used to manage production. They do not communicate between themselves.	Planning done in Excel: Most of the communication from the planning department is distributed through non-standard Excel spreadsheets.	Unclear role on who updates MES data: There is no designated person or standard operating procedure.
No procedure for updating schedule: There are no set rules and timelines for production schedule release.	Soft system: Machine shop does not need MES to function. Urgent or inconvenient work can bypass MES.	No systems link: There is incomplete communication between systems. Data regularly has to be transferred manually.
Operators work on jobs not available in MES: Jobs that are delivered to or selected by operators are not planned in MES.	Operators can't punch jobs into MES every time: Various technical issues prevented the clocking of jobs into MES.	There are too many instances of clocking on paper: Where an operator cannot (for any reason) clock work on the MES system he will instead just note it on paper.
Too many jobs in MES: Invalid work is entering the system making navigation difficult.	Actual times are skewed by operators to seem closer to standard times: Operators can cheat on their performance figures by entering any time values they chose.	Completed jobs showing in system: Jobs previously completed by the operator are returning to MES and showing as to-be-machined.
Material not at machine: There is no material available for the job which MES specifies as next in line.	Operators don't know what to produce: Operators receive so many mixed messages that they no longer know what they need to produce.	

It was identified that three distinct systems (see Figure A-1) supplemented the MRP with scheduling, shop floor control, and production execution. There was no logic dictating flow or interrelationship between the systems. Furthermore, there was no hard link between MES and any other system. Using the original (more entrenched) systems, MES could be completely bypassed.

Figure A-1 shows that work instructions did not have to pass through either the Kanban or MES system before machining. This is depicted by no solid black arrow link (these links are required and the process cannot continue without them being actioned). On the other hand, unavoidable soft links are depicted as dashed black arrows (the overall process can continue without the link being actioned, but the operations following that link cannot be), and avoidable soft links are depicted as red arrows (both the overall process and the operations following the link can continue without them being actioned). The MES system is linked entirely by dashed arrows and runs in parallel with Kanban system. The ramification of this is that when only some of the production data is captured by each system, neither of the systems is able to accurately account for the current state of production. This can be reconciled by the ERP but the process falls behind real-time by a number of days making the information far less valuable once it is finally made available.

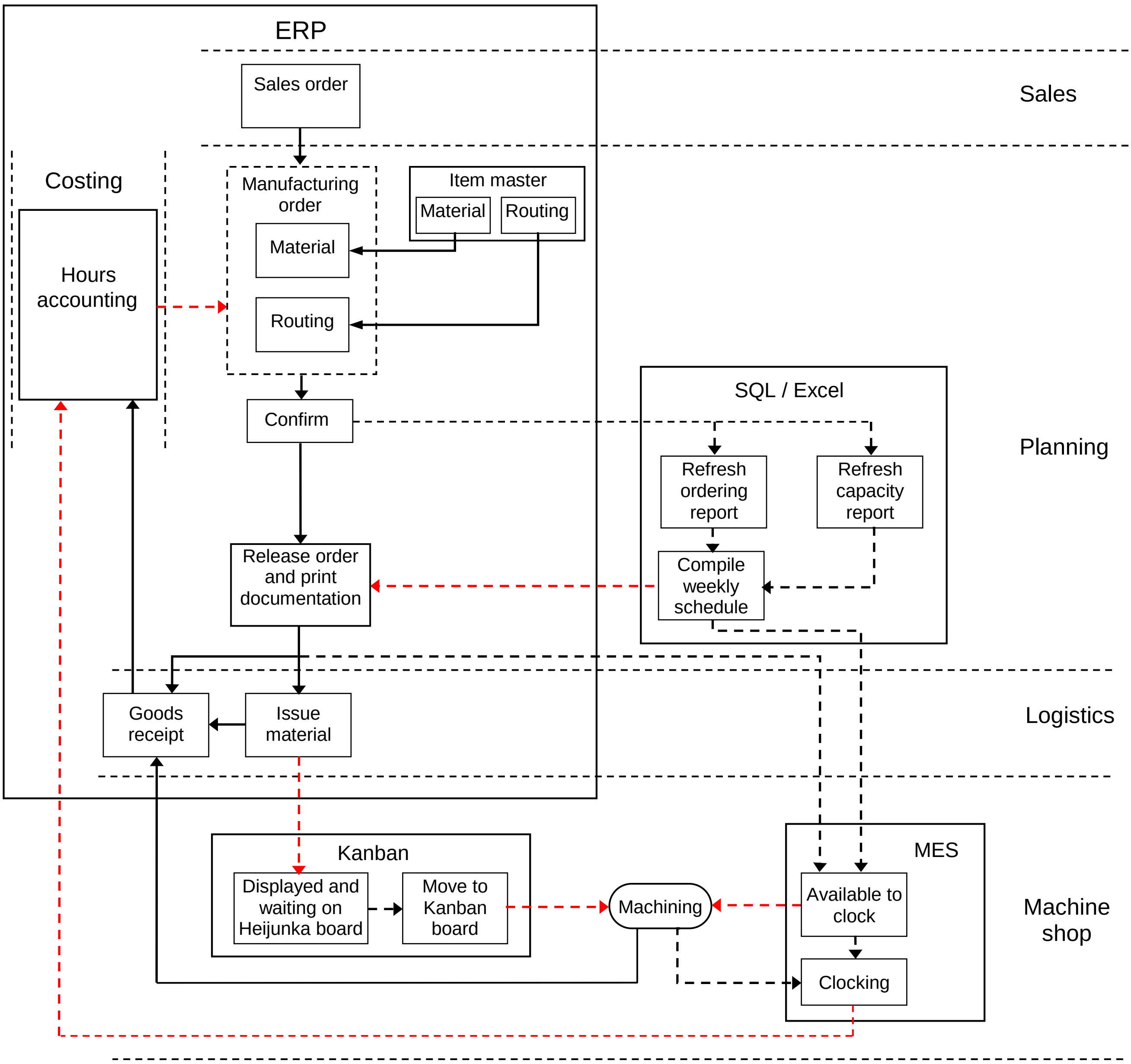


Figure A-1: Production systems diagram (original state).

Operator Buy-in

The perceived symptoms for this issue theme (as they were described in the workshops) are summarised in Table A-2.

Table A-2: Operator buy-in symptoms

Irregular clocking: Operators need to be put under pressure to clock otherwise the task gets abandoned.	Not synchronising: Operators do not post work at regular intervals but rather in batches.	All events are not logged: Operators log events selectively.
Frustration due to inconsistencies: Operators express their dislike for the system and their unwillingness to use it, citing some issue they would commonly experience.	Task does not feel like part of the operator's job: Operators state that interfacing with the system is not part of their job and they feel that they shouldn't have to do it.	

Operators would not only express their dissatisfaction with the system but would also find ways to circumvent it whenever possible. With incorrect and irregular clocking, the data gathered from the system becomes difficult to interpret. When probed further, they explained that they were dissatisfied about being measured using an inaccurate system.

The operators have only a very limited understanding of the purpose of the system, and many have concluded that its purpose is to measure their performance. This in turn creates an additional frustration in that using the system actually detracts from their performance because of the added administrative burden.

With no operator buy-in, continuous improvement and troubleshooting faults becomes difficult. In addition, rather than addressing problems when they arise, operators will drop the system and revert to the previous one.

Software Interface

The perceived symptoms for this issue theme (as they were described in the workshops) are summarised in Table A-3.

Table A-3: Software interface issue symptoms

Inputting data is complicated: There are too many variables for operators to capture.	Difficult navigation: It is not easy to pinpoint the job being worked on in the system.	Standardised input: Different operators will input different codes for the same task.

The software interface was repeatedly customised in order for the operator to be able to log and handle every variation of every scenario conceivable on the shop floor. This led to an excessively complicated input interface. Even with extensive training operators could not agree on how to interpret various scenarios. To add to the complexity, operators were discouraged from clocking certain activities because of the negative impact they had on departments outside of the machine shop.

Low-Quality Data Fed Into the System

The perceived symptoms for this issue theme (as they were described in the workshops) are summarised in Table A-4.

Table A-4: Low quality data fed into the system symptoms

Machine shop administrators adjust routings manually: Routings are the paths which a part follows through the machine shop. Where the path in the system is incorrect, the administrator needs to update it manually.	Someone is not always available to make changes: No administrator is available during night shift to update routings.	Jobs don't go through the machine shop according to their routings: Even when the routings are correct, anomalies like breakdowns and overloading result in deviations.
Incorrect standard times: These are the expected times that a job should spend at a machine.	Standard times are manually updated to equal the actual times: Because team leaders know that standard times are inaccurate, it is difficult to say how long a job should have taken. Most of the time operators are given the benefit of the doubt as to the time taken.	Unrealistic absorption and recovery: These are financial measures meant to determine if the machine shop has been running efficiently.

Inaccurate master data created instability once it was transferred to the MES system. Incorrect standard times meant that schedules could not be adhered to, machine efficiencies appeared to be random, and operator effectiveness (used to measure employee performance) was inaccurate. Incorrect routing data meant that jobs were delivered to machines where they could not be done. Item data was therefore not at the point of machining in time and the costing department then had to reconcile the discrepancy between standard and actual cost.

The cumulative effect was a loss of control and effectiveness for the MES system.

Single Point of Control

The perceived symptoms for this issue theme (as they were described in the workshops) are summarised in Table A-5.

Table A-5: No single point of control symptoms

<u>There is no way to see where issues lie:</u> There is no structured data format for use by decision makers.	<u>Simple visual representation:</u> While data on the day's activities could be derived, it is not represented functionally.	<u>Quick response:</u> The lag in data availability does not make MES a useful tool for addressing real time issues.
<u>Management needs to be able to draw graph data from MES:</u> Management is not able to identify trends from system use.		

When investigating how the above requirements were currently being met (or partially met), numerous methods of data representation were identified. They were all methods developed internally, in an unaudited manner. Both the calculations behind the data were unverified and the source of the data was unverified. Certain individuals used various sources because they know that there were discrepancies in the results. This issue was separated from misalignment because it dealt with data representation rather than data derivation as the system misalignment issue did.

To be useable, data from MES has to be extracted from the system and manipulated. Only a few individuals are able to do this. Furthermore, this data is not available in real time for quick decision-making.

The MES system developer did provide a module for data representation but the data was either irrelevant for WMMEA's purpose or the methods of calculating parameters (although not incorrect) are not aligned to WMMEA standards.

Incomplete Functionality

The perceived symptoms for this issue theme (as they were described in the workshops) are summarised in Table A-6.

Table A-6: Incomplete functionality symptoms

System does not have automatic data cleaning and updating: Data must be micro managed or it crowds the system.	System does not take into account scrap and rework: These factors need to get accounted for in a separate system.	Software lags or hangs during high usage: The operator spends excessive time at the MES terminal.
System doesn't accommodate alternative routings: Alternative routings do exist but are preselected and cannot be changed once in the MES system.	Parts are not always loaded according to the routings: Machine constraints and urgency often create a need to make alternative plans for machining.	Quality issues not recorded at the point of machining: Downtimes caused by quality issues go unnoticed.
No real time clocking: Capturing of work follows the work done. In order to have a live system capturing must happen ahead of the work.	No material management: The software does not align the material in production to the ERPs warehousing functionality.	No accompanying calibration data available on the system: this information has to be delivered through other means.

The following functionality gaps were identified:

1. Real time clocking: The software supplier stated that the system provided real time clocking. However on analysis, it was determined that for practical purposes, the data clocking was not in real time but rather was always lagging by one operation; the data was reflected in real time but the system did not make provision for capturing that data in real time.

2. JIT delivery: By not communicating material data with the ERP system, the MES system is unable to dictate where and when material is needed on the shop floor.

3. Capturing quality issues: Not being able to account for quality issues leaves blind spots in the day's activity making MES data inaccurate. This has to be reconciled outside of the system creating a delay in the reporting of quality issues.

4. Response speed and stability: System lag had a noticeable impact on the time spent clocking work. After investigation, this was determined to be due to poor IT infrastructure. Operators spend on

average 15 per shift minutes capturing work, 10 minutes due to slow system response, and 5 minutes addressing other system issues (such as system crashes and network inconsistencies).

Roles and Responsibilities

The perceived symptoms for this issue theme (as they were described in the workshops) are summarised in Table A-7.

Table A-7: Roles and responsibilities symptoms

No access for key users: Key users have been identified who have no access to or knowledge of the system	No skills matrix: It is unclear who is able to perform which functions. Employees need to know who can replace who and who can train in each area.	Operators understanding: Operators do not know and disagree on what their roles are in respect to the MES system. Simple tasks get neglected.
Breakdowns take too long to resolve: Breakdowns get reported in an inefficient manner having to escalate slowly over time until an external consultant is brought in to troubleshoot.		

Issues that arise in this issue theme are hard to identify, communicate, and take a long time to address.

For example:

1. A terminal at a machine will stop working.
2. The operator will notify the shift leader and continue his work outside the system.
3. The shift leader will eventually notify IT who are not responsible for the system.
4. The issue will go unaddressed.
5. When somebody eventually takes the initiative to correct the issue, the corrective measure is usually to contact the MES system supplier.
6. The supplier will come to site (at high cost) only to discover a trivial error (e.g. the cable is unplugged).

Additionally, everybody who is involved is only responsible to action his department's workload. There is no combined responsibility to ensure the system functions as a whole. This leads to bad and inconsistent data overwhelming the MES system over time.

All this in turn created a slow and illegible system that is difficult to troubleshoot. Bad system logic and incomplete integration is hidden behind the clutter of bad data.

Backup System

The perceived symptoms for this issue theme (as they were described in the workshops) are summarised in Table A-8.

Table A-8: Backup system issue theme symptoms

Computers go down often: Technical hardware issues prevent system use.	System gives errors to users: Technical software or network issues prevent system use.	Too much manual clocking: Lack of knowledge prevents system use.

It was determined during the solution management stage (that follows) that the older Kanban system for managing production would have to be removed. This means that the old way of managing the machine shop would no longer be available. Considering that MES is highly dependent on factors with known limited stability (such as power supply or network availability), a quick-to-implement backup system is needed.

In addition to this, an action plan for getting MES back on track quickly needs to be available.

APPENDIX B: Benefit Profiles

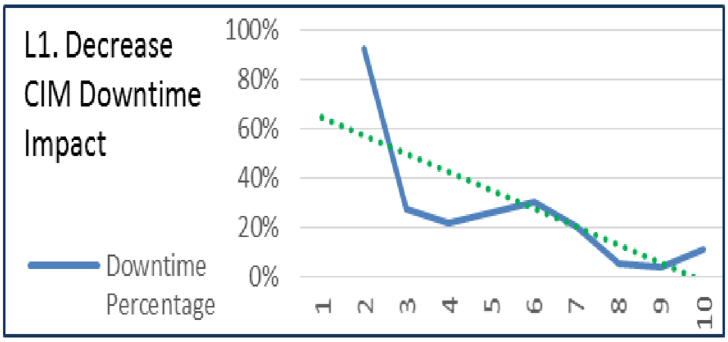
Lower-Level Benefits

Lower-level benefits are those found mainly within the MES system. Figure B-1 to Figure B-8 show the benefit profiles of the lower-level benefits.

Benefit Profile – L1.		
Short Description:	Decrease MES downtime impact.	
Explanation:	It is expected that due to a number of unavoidable factors, the MES system will occasionally become either partially or completely unavailable. These downtimes will in turn have a negative impact on the system usage. Some common causes of system downtime are power surges, network availability, hardware crashes, software crashes, slow response to repair, incomplete user profiles, and untrained users. To be classified as downtime, the system must be completely unusable by the operator.	
Preceding Benefit(s):	Preceding 1:	Enabler. Project 8 – Backup and recovery system.
	Weight 1:	100%
Resulting Benefit(s):	Resulting 1:	I1. Increase usage.
External Influence(s):	Influence 1:	None.
	Weight 1:	n/a
Measurement:	Downtime is measured as a percentage of operators who used the system per shift versus the total number of operator shifts in the given time period. The measurement is based on the fact that had the system been “up”, the operator would have captured something within the shift. Having had not captured anything (but still reported having done work) reliably implies that the system was not available for him to use.	
Target:	Decrease downtime.	

Data:	See table and chart below

Period	Downtime Percentage
1	#N/A
2	92%
3	27%
4	22%
5	#N/A
6	30%
7	20%
8	5%
9	4%
10	11%



* Costing system was not available during period 5. Shifts were not accurately recorded.

Benefit Owner:	Machine shop manager.

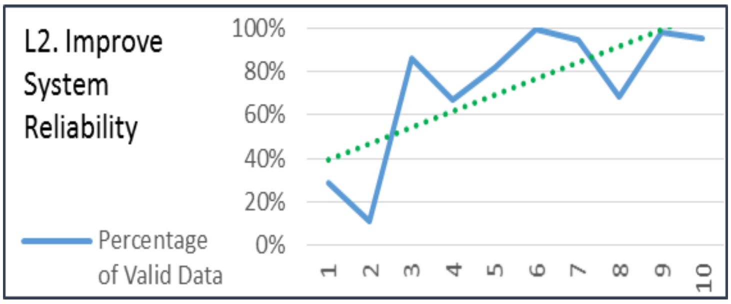
Figure B-1: Benefit L1. Decrease MES downtime impact.

Benefit Profile – L2.

Short Description:	Improve system reliability	
Explanation:	Reliability describes the ability of the system to function correctly consistently. This benefit focuses on how reliably data in the system is handled. Issues could arise form, data failing to enter the system, incorrect data entering the system, or data not being processed by the system.	
Preceding Benefit(s):	Preceding 1:	Enabler. Project 1 – System alignment.
	Weight 1:	100%
Resulting Benefit(s):	Resulting 1:	I1. Increase Usage.
External Influence(s):	Influence 1:	None.
	Weight 1:	n/a

Measurement:	System reliability is measured as the percentage of order events handled by the MES system versus events which had to be done by an administrator to correct data.
Target:	Increase % of valid data.
Data:	

Date	Percentage of Valid Data
1	29%
2	11%
3	86%
4	67%
5	82%
6	99%
7	94%
8	69%
9	98%
10	95%



Benefit Owner:	Planning manager.

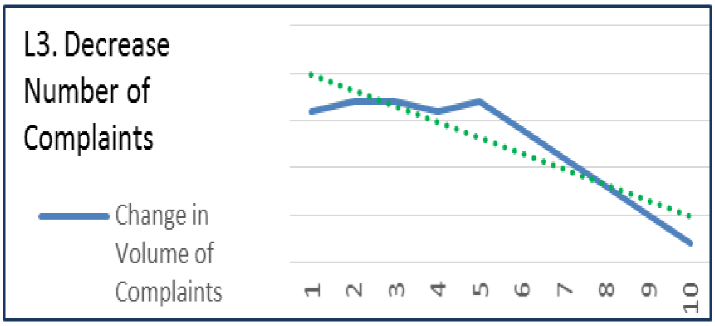
Figure B-2: Benefit L2. Improve system reliability.

Benefit Profile – L3.

Short Description:	Decrease number of complaints.	
Explanation:	When operators are unable to do what is required of them or are for any reason unhappy with the system, they will complain. Addressing complaints will in turn remove barriers to system use and will result in increased usage.	
Preceding Benefit(s):	Preceding 1:	Enabler. Project 2 – Operator buy-in.
	Weight 1:	70%
	Preceding 2:	Enabler. Project 3 – Software interface.
	Weight 2:	30%

Resulting Benefit(s):	Resulting 1:	I1. Increase Usage.
External Influence(s):	Influence 1:	None.
	Weight 1:	n/a
Measurement:	Increase or decrease in number of complaints over the given periods as experienced by the team leader, process engineer, and machine shop manager. Since only a trend is required, and quantities are not accurately recorded, the stakeholders were asked to comment on whether the number of complaints has increased, stayed the same, or decreased over the given time period. Each “increased” answer is given a 1, “stayed the same” is given a 0, and “decreased” is given a -1. The answers from the three stakeholders are then summed together and plotted cumulatively.	
Target:	Decrease number of complaints.	
Data:		

Period	Change in Volume of Complaints
1	1
2	2
3	2
4	1
5	2
6	-1
7	-4
8	-7
9	-10
10	-13



Benefit Owner:	Machine shop manager.

Figure B-3: Benefit L3. Decrease number of complaints.

Benefit Profile – L4.

Short Description:	Increase accuracy of data.	
Explanation:	When data is incorrectly captured by operators, the picture that gets painted down the line becomes less and less valuable. Part actual costs become skewed, production variations become hard to analyse, and trends are skewed. This benefit differs from the system reliability benefit in that the inaccuracies in data come from operator mistakes. System data needs to represent the true state of the shop floor at any time.	
Preceding Benefit(s):	Preceding 1:	Enabler. Project 3 – Software interface.
	Weight 1:	70%
	Preceding 2:	I1. Increase usage.
	Weight 2:	30%
Resulting Benefit(s):	Resulting 1:	I2. Improve decision making ability.
External Influence(s):	Influence 1:	None.
	Weight 1:	n/a
Measurement:	Accurately captured data as a percentage of all data captured over a period. This measurement is achieved by comparing raw data from MES with the reconciled data in the ERP.	
Target:	Increase % of accurately captured data.	
Data:		

Period	Percentage Accurately Captured
1	#N/A
2	30%
3	44%
4	52%
5	62%
6	60%
7	68%
8	64%
9	73%
10	73%

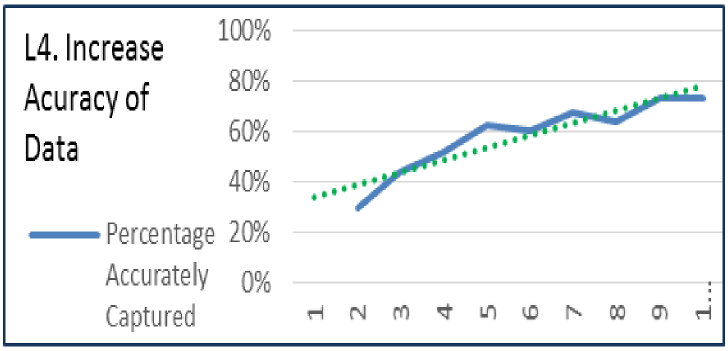
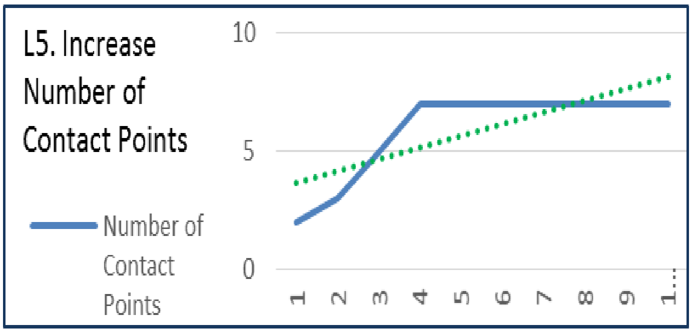
	
Benefit Owner:	Process engineer.

Figure B-4: Benefit L4. Increase accuracy of data.

Benefit Profile – L5.		
Short Description:	Increase number of contact points.	
Explanation:	In order for management and support staff to interact with the MES system and obtain the necessary information for decision making, contact points need to be readily available and easy to use. Data needs to be from the same source but displayed in the most relevant manner for the task at hand.	
Preceding Benefit(s):	Preceding 1:	Enabler. Project 5 – Single point of control.
	Weight 1:	100%
Resulting Benefit(s):	Resulting 1:	I3. Increase usage for decision making.
	Resulting 2:	I4. Decrease response time.
External Influence(s):	Influence 1:	None.
	Weight 1:	n/a
Measurement:	Count of the number of contact points that management has available to interact with the system. Multiple contact points of the same kind in the same area are not counted.	
Target:	Increase number of contact points.	
Data:	Contact points and date made available: 8. Laptop program, Initial. 9. Workflow management, Dec 2013. 10. Status indicators, Mar 2014. 11. Tablet access, Jul 2014. 12. Cell phone access, Jul 2014.	

	13. SMS notification, Nov 2014. 14. Operator terminal, Nov 2014*. Total number of contact points: 7 *while the operator terminals were always available, the interface was upgraded to signal a full screen machine status report while the terminal was not being operated.

Period	Number of Contact Points
1	2
2	3
3	5
4	7
5	7
6	7
7	7
8	7
9	7
10	7

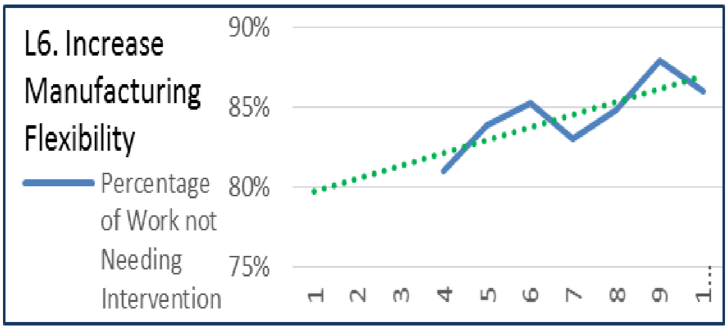


Benefit Owner:	Process engineer.

Figure B-5: Benefit L5. Increase number of contact points.

Benefit Profile – L6.

Short Description:	Increase manufacturing flexibility.
Explanation:	In order to maintain steady (efficient) flow of parts the machine shop requires accurate capacity scheduling. It is not always possible to adhere to the schedule as unforeseen events occur regularly (machine breakdowns or urgent orders for example). To make the problem

<table>
<tr><td></td><td colspan="2">worse, inaccurate routing data also regularly derails production plans. In order to be able to handle these interruptions, the MES system needs to be flexible enough to account for and adjust to the deviation from the planned state.</td></tr>
<tr><td rowspan="2">Preceding Benefit(s):</td><td>Preceding 1:</td><td>Enabler. Project 4 – Quality of data.</td></tr>
<tr><td>Weight 1:</td><td>100%</td></tr>
<tr><td>Resulting Benefit(s):</td><td>Resulting 1:</td><td>I4. Decrease response time.</td></tr>
<tr><td rowspan="2">External Influence(s):</td><td>Influence 1:</td><td>None.</td></tr>
<tr><td>Weight 1:</td><td>n/a</td></tr>
<tr><td>Measurement:</td><td colspan="2">The percentage of variances that pass through the machining process without the need for manual system intervention during or after manufacturing. All orders with a variance to the standard routing were analysed. The percentage of these that the system was able to handle is measured.</td></tr>
<tr><td>Target:</td><td colspan="2">Increase the % of scheduled work that passes through the machining process without manual intervention.</td></tr>
<tr><td>Data:</td><td colspan="2">
<table>
<tr><th>Period</th><th>Percentage of Work not Needing Intervention</th></tr>
<tr><td>1</td><td>#N/A</td></tr>
<tr><td>2</td><td>#N/A</td></tr>
<tr><td>3</td><td>#N/A</td></tr>
<tr><td>4</td><td>81%</td></tr>
<tr><td>5</td><td>84%</td></tr>
<tr><td>6</td><td>85%</td></tr>
<tr><td>7</td><td>83%</td></tr>
<tr><td>8</td><td>85%</td></tr>
<tr><td>9</td><td>88%</td></tr>
<tr><td>10</td><td>86%</td></tr>
</table>


</td></tr>
<tr><td>Benefit Owner:</td><td colspan="2">Process engineer.</td></tr>
</table>

Figure B-6: Benefit L6. Increase manufacturing flexibility.

Benefit Profile – L7.

Short Description:	Reduce administrative workload.	
Explanation:	An operator's shift lasts 8 hours. He however only adds value to a product during the time he spends working on a job (value-adding time). Various forms of administrative work detract from this available time for value adding operations. Interacting with the MES system is non-value-adding time. This time must therefore be minimised as much as possible as it is presents an opportunity cost to the machine shop.	
Preceding Benefit(s):	Preceding 1:	Enabler. Project 6 – Increased functionality.
	Weight 1:	100%
Resulting Benefit(s):	Resulting 1:	H4. Increase machine availability.
External Influence(s):	Influence 1:	None.
	Weight 1:	n/a
Measurement:	The time that operators spend interacting with the system as experienced by the team leader and process engineer. Since only a trend is required, and quantities are not accurately recorded, the stakeholders were asked to comment on whether the administrative workload has increased, stayed the same, or decreased over the given time period. Each "increased" answer is given a 1, "stayed the same" is given a 0, and "decreased" is given a -1. The answers from the two stakeholders are then summed together and plotted cumulatively.	
Target:	Decrease interaction time.	
Data:	(see table below)	

Date	Change in Time Spent Interacting with System
1	1
2	1
3	2
4	0
5	0
6	-2
7	-2
8	-4
9	-6
10	-8

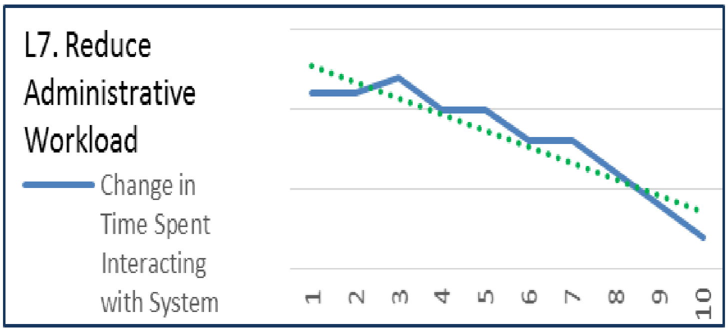
	
Benefit Owner:	Process engineer.

Figure B-7: Benefit L7. Reduce administrative workload.

Benefit Profile – S1.		
Short Description:	Decrease consulting costs.	
Explanation:	All training and system updates provided by a supplier are charged at an hourly rate. Therefore, any training or system update that can be done in-house is an equivalent cost saving at the same rate.	
Preceding Benefit(s):	Preceding 1:	Enabler. Project 7 – Roles and responsibilities.
	Weight 1:	100%
Resulting Benefit(s):	Resulting 1:	None.
External Influence(s):	Influence 1:	None.
	Weight 1:	n/a
Measurement:	The monthly equivalent cost of training and updating the system had it been done by the software supplier.	
Target:	Any positive value	
Data:	Not measured. This supporting benefit does not form part of the requirements for this report.	
Benefit Owners:	Project manager.	

Figure B-8: Supporting benefit S1. Decrease consulting costs.

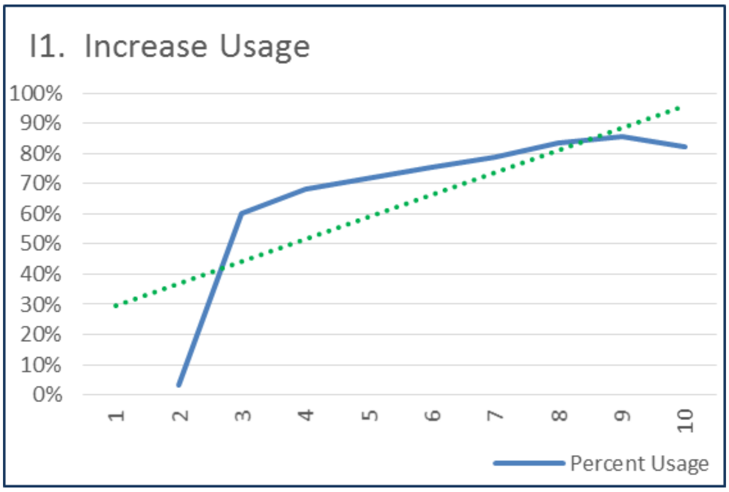
Intermediate Benefits

Intermediate benefits are those mainly found outside the MES system but within the machine shop system. Figure B-9 to Figure B-12 show the benefit profiles of the intermediate benefits.

Benefit Profile – I1.		
Short Description:	Increase usage.	
Explanation:	When the MES system was launched, the machine shop didn't switch overnight over to the radically-different method of production. The system ran in parallel to the original Kanban system, employees were trained to use the system over time, and functions were added gradually. In addition, technical issues hampered the complete function of the system. As the system matures and issues are resolved, usage needs to increase.	
Preceding Benefit(s):	Preceding 1:	L1. Decrease MES downtime impact.
	Weight 1:	20%
	Preceding 2:	L2. Improve system reliability.
	Weight 2:	50%
	Preceding 3:	L3. Decrease number of complaints.
	Weight 3:	30%
Resulting Benefit(s):	Resulting 1:	H1. Improve schedule adherence.
	Resulting 2:	L4. Increase accuracy of data.
External Influence(s):	Influence 1:	None.
	Weight 1:	n/a
Measurement:	Increase the % of total work which is done through the MES system. Measured by comparing order-operations captured in MES vs captured in Hours Accounting (ERP costing module). Counted even if captured incorrectly.	
Target:	Increase in % of work.	

Data:

Date	Percent Usage
1	#N/A
2	3%
3	60%
4	68%
5	#N/A
6	75%
7	79%
8	84%
9	86%
10	82%



* Costing system was not available during period 5. Shifts were not accurately recorded.

Benefit Owner:	Machine shop manager.

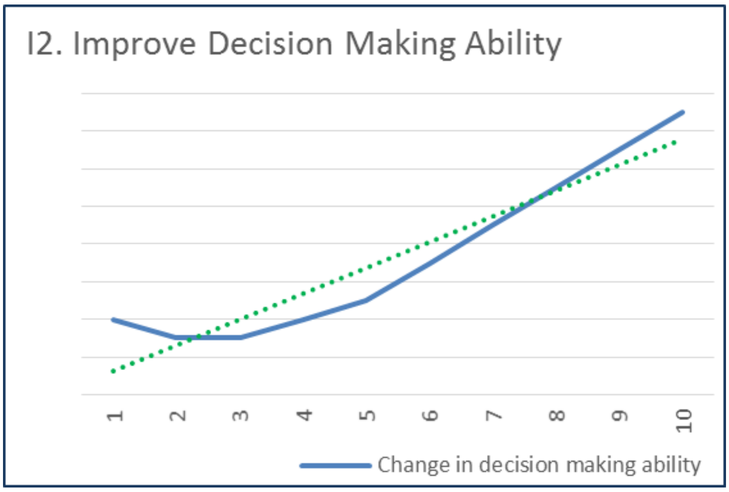
Figure B-9: Benefit I1. Increase usage.

Benefit Profile – I2.

Short Description:	Improve decision making ability.	
Explanation:	This benefit falls in the same group as benefit I3 – decision making. By having an accurate, data-driven, picture of the true state of production, management is able to reliably make decisions that will improve the performance of the machine shop.	
Preceding Benefit(s):	Preceding 1:	L4. Increase accuracy of data.
	Weight 1:	100%
Resulting Benefit(s):	Resulting 1:	H2. Reduce age of WIP.

	Resulting 2:	H3. Decrease production time variances.
External Influence(s):	Influence 1:	None.
	Weight 1:	n/a
Measurement:	The improvement in management’s decision making ability as experienced by the process engineer and the machine shop manager. These stakeholders were asked to comment on whether their ability to make decisions has increased, stayed the same, or decreased over the given time period. Each “increased” answer is given a 1, “stayed the same” is given a 0, and “decreased” is given a -1. The answers from the two stakeholders are then summed together and plotted cumulatively.	
Target:	Improve decision making ability.	
Data:		

Date	Change in decision making ability
1	0
2	-1
3	-1
4	0
5	1
6	3
7	5
8	7
9	9
10	11



Benefit Owner:	Machine shop manager.

Figure B-10: Benefit I2: Improve decision making ability.

Benefit Profile – I3.

Short Description:	Increase usage for decision making.	
Explanation:	This benefit falls in the same group as benefit I2 – decision making. In order for the MES system to be used for decision making, the data generated needs to be presented in a relevant format and in an accessible manner.	
Preceding Benefit(s):	Preceding 1:	L5. Increase number of contact points.
	Weight 1:	100%
Resulting Benefit(s):	Resulting 1:	H2. Reduce age of WIP.
	Resulting 2:	H3. Decrease production time variances.
External Influence(s):	Influence 1:	None.
	Weight 1:	n/a
Measurement:	The system usage for decision making as experienced by the process engineer and the machine shop manager. These stakeholders were asked to comment on whether their usage of the system for decision making has increased, stayed the same, or decreased over the given time period. Each "increased" answer is given a 1, "stayed the same" is given a 0, and "decreased" is given a -1. The answers from the two stakeholders are then summed together and plotted cumulatively.	
Target:	Increase usage for decision making.	
Data:		

Date	Change in usage for decision making
1	0
2	-1
3	-1
4	0
5	1
6	3
7	5
8	7
9	9
10	11

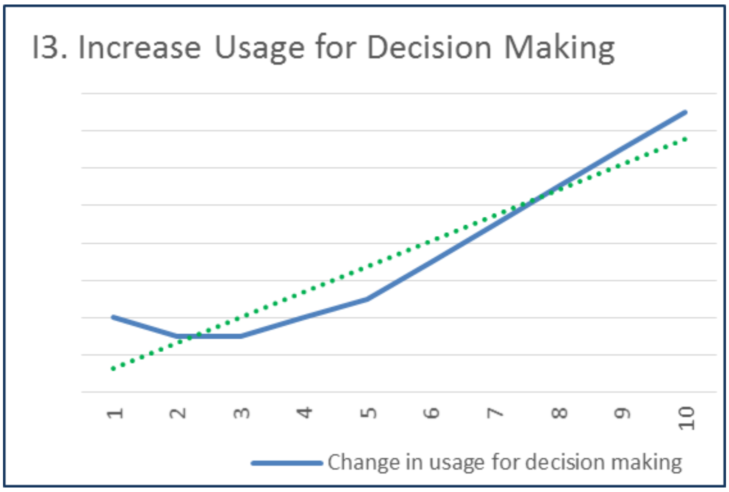
	
Benefit Owner:	Machine shop manager.

Figure B-11: Benefit I3. Increase usage for decision making.

Benefit Profile – I4.

Short Description:	Decrease response time.	
Explanation:	The MES system is able to process key events that take place on the shop floor, in real time, and communicate them to the relevant departments. The department will in turn respond to the event and take the necessary action.	
Preceding Benefit(s):	Preceding 1:	L5. Increase number of contact points.
	Weight 1:	30%
	Preceding 2:	L6. Increase manufacturing flexibility.
	Weight 2:	30%
	Preceding 3:	Enabler. Project 7 – Roles and responsibilities.
	Weight 3:	20%
	Preceding 4:	Enabler. Project 6 – Increased functionality.
	Weight 4:	20%
Resulting Benefit(s):	Resulting 1:	H4. Increase machine availability.
External Influence(s):	Influence 1:	None.
	Weight 1:	n/a
Measurement:	Lost time as % of total uptime. This measurement is limited to the time it takes a supporting function to respond to an issue. An issue that takes long to correct (like a complete machine breakdown) will not contribute to lost time but rather a decrease in total uptime. The	

	measurement is the sum of all downtime (indirect hours) which requires external support as a percentage of uptime (direct hours) + indirect hours which can be addressed by the operator.
Target:	Decrease % of lost time.
Data:	(see table and chart below)
Benefit Owner:	Each department's manager for their related lost time category.

Date	Percentage Lost Time
1	#N/A
2	4%
3	7%
4	8%
5	9%
6	7%
7	10%
8	9%
9	10%
10	8%

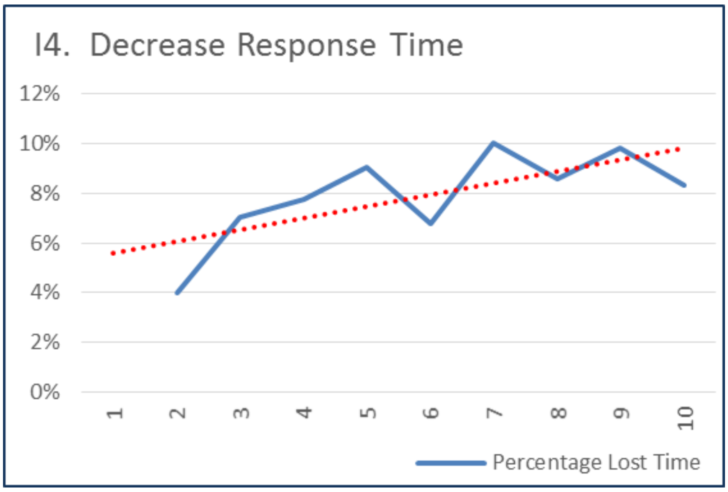


Figure B-12: Benefit I4. Decrease response time.

Higher-Level Benefits

Higher-level benefits are those mainly found to be the outcomes of the machine shop system (such as KPI measurements). Figure B-13 to Figure B-16 show the benefit profiles of the higher-level benefits.

Benefit Profile – H1.		
Short Description:	Improve schedule adherence.	
Explanation:	To produce what is required and achieve a favourable OTD, the machine shop produces to a finite-capacity schedule. Deviations from schedule happen due to both technical and operational reasons. While deviations are acceptable, the risk of failing to deliver on-time to a customer increases when the schedule is not adhered to. The MES system guides production according to the schedule it receives.	
Preceding Benefit(s):	Preceding 1:	I1. Increase usage.
	Weight 1:	80%
Resulting Benefit(s):	Resulting 1:	Objective. O1. Maximise availability and OTD.
External Influence(s):	Influence 1:	Supply chain may (for strategic reasons or through bad management) place urgent orders (in the form of spike loading or reduced lead time) that will necessitate a disruption in the planned production schedule. This leads to decreased schedule adherence. Frequency is however low.
	Weight 1:	20%
Measurement:	The average number of weekly manufactured not-on-schedule parts for the given date range.	
Target:	Decrease number of unscheduled parts.	
Data:		

Date	Number of Unscheduled Parts
1	#N/A
2	#N/A
3	92
4	71
5	#N/A
6	101
7	87
8	48
9	40
10	23

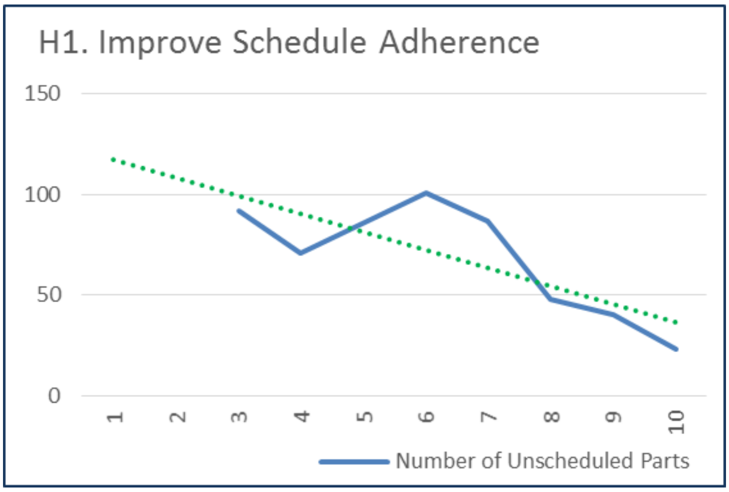
	 * There was no scheduled production at the start of the year (period 5).
Benefit Owner:	Planning manager.

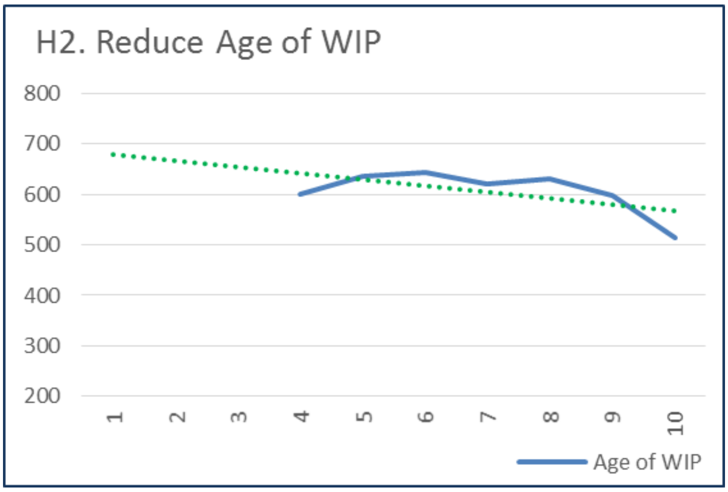
Figure B-13: Benefit H1. Improve schedule adherence.

Benefit Profile – H2.

Short Description:	Reduce age of Work In Progress (WIP).	
Explanation:	The machine shop has an allowable lead time on production of two weeks. Problem items can however take longer and if not managed will pile up. Reducing the age of WIP not only reduces the cost of WIP but also facilitates good flow through the machine shop.	
Preceding Benefit(s):	Preceding 1:	I2 & I3. Decision making group.
	Weight 1:	100%
Resulting Benefit(s):	Resulting 1:	Objective. O1. Maximise availability and OTD.
External Influence(s):	Influence 1:	None
	Weight 1:	n/a
Measurement:	Total age of WIP at the end of each time period.	
Target:	Decrease the age of WIP.	

Data:	(see table and chart below)

Date	Age of WIP
1	#N/A
2	#N/A
3	#N/A
4	600
5	635
6	645
7	621
8	631
9	597
10	514



Benefit Owner:	Machine shop manager.

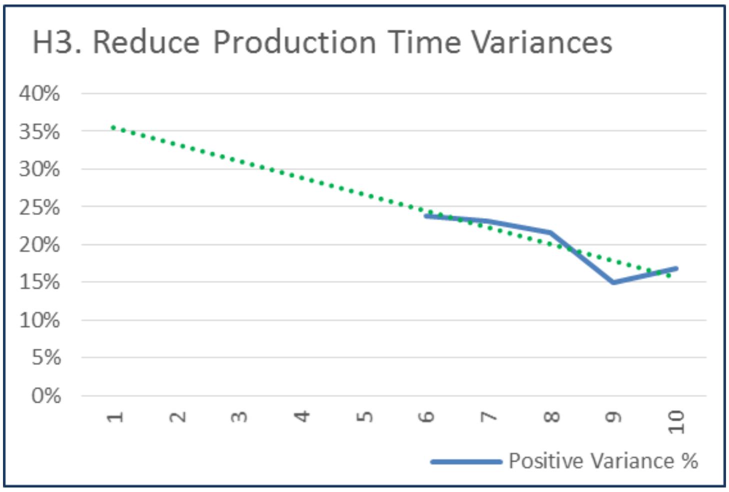
Figure B-14: Benefit H2. Reduce the age of WIP.

Benefit Profile – H3.

Short Description:	Reduce production time variances.
Explanation:	The production capacity and cost is defined in terms of standard production times. These are times specified for each machine-part-operation combination. They are derived through time studies. It is expected that actual machining times will vary from the standard to an extent (due to variability in man, method, machine, or material). Lower variation means more stable and predictable production. The added complication is the inaccuracy in the standard times which makes achieving targets difficult, even under ideal conditions.

Preceding Benefit(s):	Preceding 1:	I2 & I3. Decision making group.
	Weight 1:	100%
Resulting Benefit(s):	Resulting 1:	Objective. O2. Maximise part value.
External Influence(s):	Influence 1:	None
	Weight 1:	n/a
Measurement:	The average positive overrun. Measurement is the actual run time minus the standard time as a percentage of standard time.	
Target:	Decrease variance.	
Data:	(see below)	

Date	Positive Variance %
1	#N/A
2	#N/A
3	#N/A
4	#N/A
5	#N/A
6	24%
7	23%
8	22%
9	15%
10	17%



Benefit Owner:	Machine shop manager.

Figure B-15: Benefit H3. Decrease production time variances.

Benefit Profile – H4.

Short Description:	Increase machine shop Overall Equipment Effectiveness (OEE).	
Explanation:	OEE is an indicative measure of the % of time during which the machine adds value to the products it machines. Machines do not add value to a product throughout the day. They need to be stopped for various reasons (such as changing tools), they fall behind on speed (when material is too hard), and they occasionally scrap work.	
Preceding Benefit(s):	Preceding 1:	I4. Decrease response time.
	Weight 1:	75%
	Preceding 2:	L7. Reduce administrative workload.
	Weight 2:	25%
Resulting Benefit(s):	Resulting 1:	Objective. O2. Maximise part value.
External Influence(s):	Influence 1:	None over the period under measurement.
	Weight 1:	n/a
Measurement:	The OEE measurement definition presented here is differs from the standard OEE definition. The measurement is the minimum of standard hours and actual hours plant output as a percentage of total labour hours available. Machine setup time is considered a lost time only to the extent by which it exceeds the standard allowable setup hours.	
Target:	Increase availability %.	
Data:		

Date	OEE
1	#N/A
2	#N/A
3	39%
4	56%
5	46%
6	58%
7	62%
8	62%
9	60%
10	60%

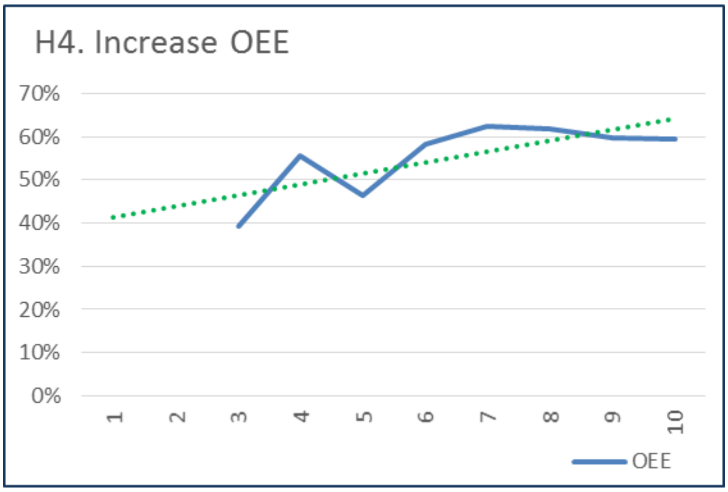
	
Benefit Owner:	Machine shop manager.

Figure B-16: Benefit H4. Increase machine availability.

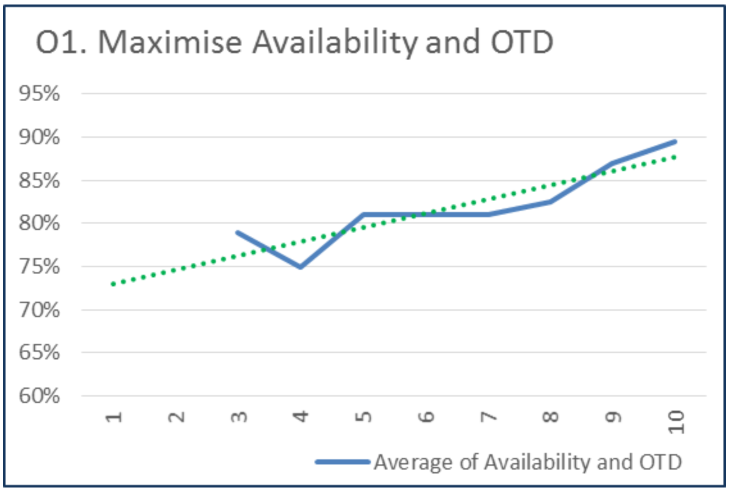
Company Objectives

Company objectives may well be outside the influence of the machine shop alone. They are usually affected by activities from various areas of the business. Figure B-17 and Figure B-18 show the benefit profiles of the company objectives.

Benefit Profile – O1.		
Short Description:	Company Objective: Maximise availability and OTD.	
Explanation:	In order to satisfy customer expectations, the company has decided to keep finished goods stock on a range of fast moving parts (MTS parts). The customer is told that he can expect delivery on any of these parts within 24 hours. The company targets to uphold this promise 89% of the time (Feb 2015 target). For items that do not move quickly (MTO parts), the company has committed to manufacture and deliver within 6 weeks of order placement. The company targets to also uphold this promise 89% of the time (Feb 2015 target).	
Preceding Benefit(s):	Preceding 1:	H1. Improve schedule adherence.
	Weight 1:	20%
	Preceding 2:	H2. Reduce age of WIP.
	Weight 2:	20%
Resulting Benefit(s):	Resulting 1:	n/a
External Influence(s):	Influence 1:	This objective is heavily influenced by the S&OP programme running in parallel to the MES initiative. The S&OP programme aims to improve delivery to customer by sharing and level loading the input demand on production from the very point of order placement.
	Weight 1:	60%
Measurement:	Availability is a measure of MTS part performance. It measures the percentage of MTS items for which stock is available at the time of order placement. OTD is a measure of MTO part performance. It measures the percentage of orders that have been completed within the promised 6 week lead time. The final measure is the average of the 2 percentages.	
Target:	Increase the average of availability and OTD.	

Data:	(see table and chart below)

Date	Average of Availability and OTD
1	#N/A
2	#N/A
3	79%
4	75%
5	81%
6	81%
7	81%
8	83%
9	87%
10	90%



Benefit Owner:	Plant manager.

Figure B-17: Objective O1. Maximise availability and OTD.

Benefit Profile – O2.	
Short Description:	Company Objective: Maximise part value.
Explanation:	The machine shop’s customer is the company warehouse to which it sells products at cost. The advantage that the machine shop has as an internal supplier is that it can provide parts to the warehouse at a lower cost than an external supplier can. In order to do this it needs to set the cost of the parts at a level that will exactly cover the running cost of its machines without making a profit. This translates into a certain part value output per hour known as the throughput rate. Through various initiatives, the company tries to make efficiency improvements which increase throughput rate. This in turn translates into lower

	part cost and increased capacity to machine parts. The increased capacity in turn provides a cost saving in terms of reducing the amount of work that needs to be done by external suppliers.	
Preceding Benefit(s):	Preceding 1:	H3. Decrease production time variances.
	Weight 1:	30%
	Preceding 2:	H4. Increase machine availability.
	Weight 2:	30%
Resulting Benefit(s):	Resulting 1:	n/a
External Influence(s):	Influence 1:	This objective is heavily influenced by the machine shop productivity programme. The productivity programme aims to increase machine shop capacity and throughput rate by (among others) upgrading machine capability, increasing availability of specialised tooling, and improving manning schedules.
	Weight 1:	40%
Measurement:	Throughput rate is a monetary value generated per hour measure on parts where there is genuine short term demand. The value generated are calculated on the amount of standard hours of work produced, in a period, at an hourly machine rate. The measurement is the standard time as a percentage of actual time averaged out within the period. Machine downtime and scrap are included in the calculation.	
Target:	Increase average throughput rate.	
Data:		

Date	Percentage of Standard Throughput Rate
1	#N/A
2	#N/A
3	78%
4	78%
5	73%
6	77%
7	88%
8	89%
9	89%
10	83%

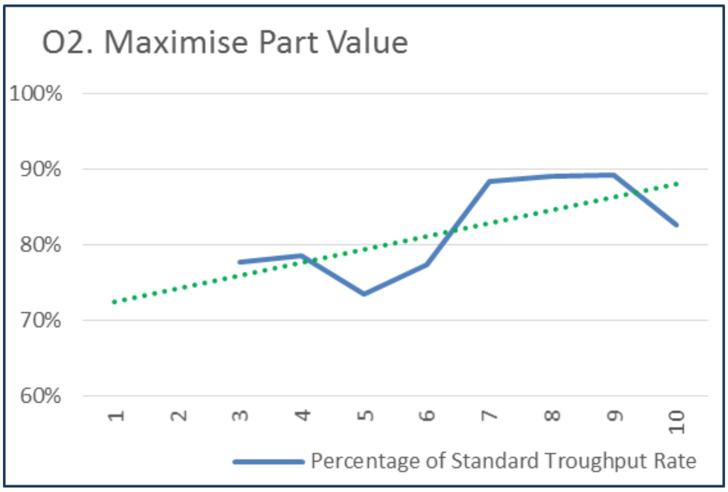
	
Benefit Owner:	Plant manager.

Figure B-18: Objective O2. Maximise part value.

APPENDIX C: Solutions Management Projects

System Alignment

This was identified as the largest contributing factor for the lack of system usage by operators. Even if all other enablers were instated, the MES system would be unable to perform as part of the company's macro system without being aligned with other systems.

The project resulted in the cessation of the Kanban system and hard-linking of the remaining systems to create a new workflow. Figure C-1 shows the systems diagram after the project has been completed (this is the revised systems diagram, Figure A-1, from Appendix A). It was achieved as follows:

- The Kanban system existed prior to the MES system but was not considered in the initial MES implementation. The system remained and was run in parallel with MES. This not only created a duplication of work but made both systems completely unreliable (the Kanban system can no longer signal for work reliably as it doesn't have a way of knowing what work MES is signalling, and vice versa). With this setup, MES becomes just an administrative task which can be bypassed by simply not using it. This is an example of a disbenefit that was created by MES. The Kanban system had to be made obsolete.

- Hard linking of systems is done to prevent execution of certain system operations while bypassing others (an example would be a printer which doesn't allow printing without the paper tray being loaded first). Automation is also a consequence of hard linking. The hard links created in this case were:
    - Between the scheduling system and ERP
    - Between ERP and MES
    - Between MES and the machining operation

The resulting process is summarised as follows:

- ERP generates orders

- All orders have to be scheduled in the scheduling system
- Scheduling system writes the schedule to ERP
- ERP releases the scheduled (sequenced) orders to MES
- MES dictates machining and material flow
- MES feeds the results back to the ERP

In Figure C-1, hard links are shown as solid black arrows (these are required and the process cannot continue without them being actioned) and avoidable soft links as dashed red arrows (both the overall process and the operations following the link can continue without them being actioned). The new red link is a backup in the event that the MES system fails.

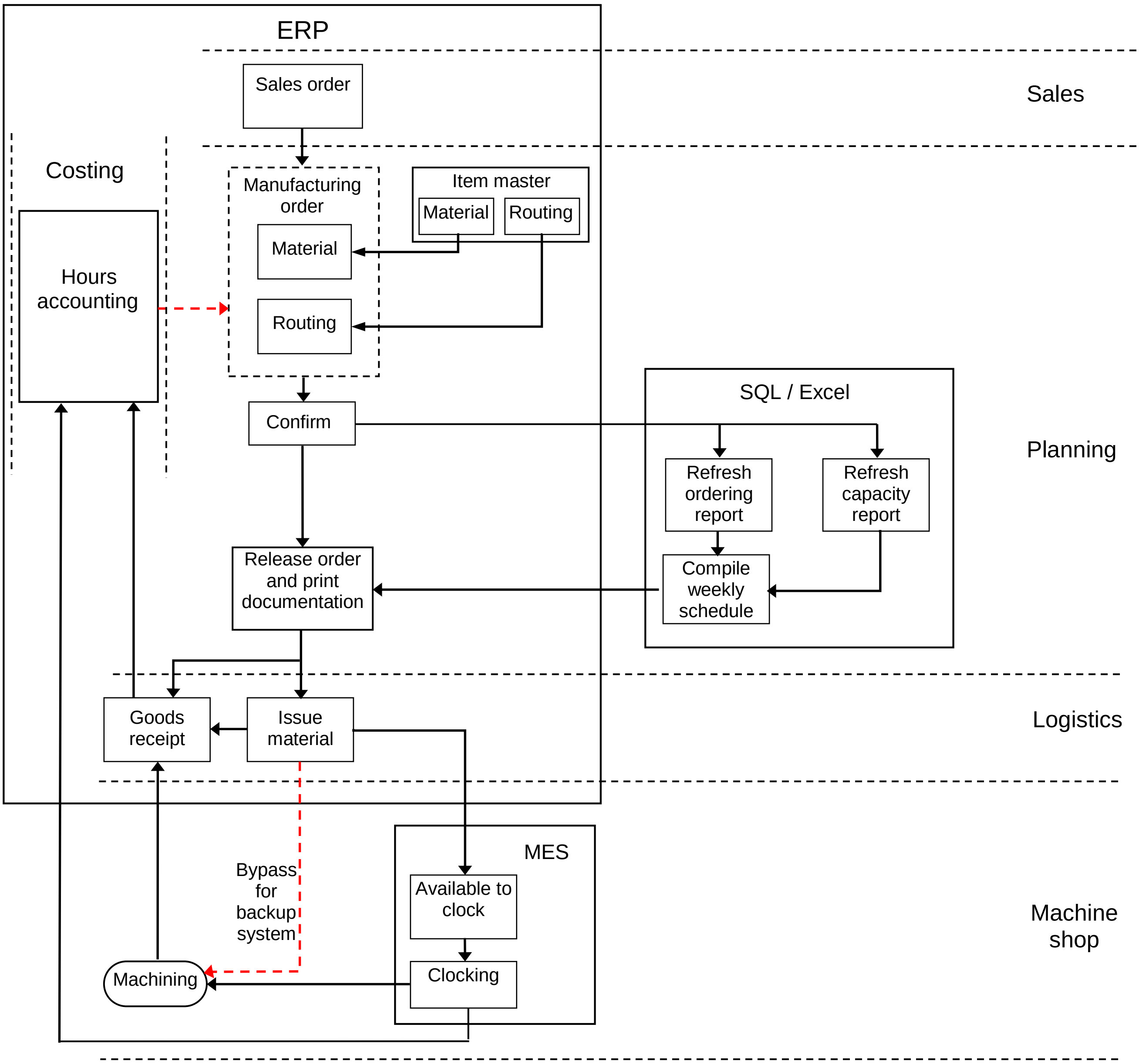


Figure C-1: Preferred (end) state systems diagram.

Operator Buy-in

It was necessary to ensure operators do feel they are being forced into using the system, but rather to perceive the system as being there to benefit both them and the company. This meant that the system needs to be made to benefit them.

The following actions brought about operator buy-in:

- Formal operator performance measurement was removed from the system and moved to the ERP costing function (while operators understood that they had to be measured, measuring them through MES created too much pressure for objective co-operation in system design).

- System functions had to benefit the operator. The following functions were identified as beneficial: Simplified clocking, short-term schedule visibility, communication on specific job issues, and providing a summary of the day’s work.

- Involvement in software interface and functionality design. The majority of new function and design testing was done alongside the operators. This gave them a chance to input their own ideas into how the software should look and then to see how it was progressing with each iteration.

- Training was continually repeated and elaborated on. Continuous retraining created confidence and familiarity with the system. In order to viably run the extended trainings that were planned, many users were trained as (uncertified) trainers. The system providers conducted only a few training sessions for the purpose of formalisation.

Software Interface

This project aimed to speed up, simplify, and standardise input to the system. It was broken down into the following two sections:

Input requirement: This was reduced from 10 to 20 fields to a maximum of 3 fields. Some were deemed as not worth spending time on, while many other could be automated (e.g. starting a new action implies the previous was completed).

Layout design: The interface was completely redesigned to be intuitive and minimise the number of clicks (and screens) needed to achieve a result.

Quality of Data

Incorrect standard times and routings could be worked around in the Kanban system because of the high level of human interaction (i.e. a planner would never bring a job to the incorrect machine because the ERP tells him to do so). In order to ensure MES routes and delivers the work accurately two actions were taken:

- Shop shift functionality was developed to allow cross-machine capturing of work. This is fed back to the ERP as a planned vs. actual variance. This both allows the system to function without assistance and creates a new set of data useful for troubleshooting inaccurate routing data.
- The statistical data collected by MES was used to target routing inconsistencies and improve standard times.

Single Point of Control

Shop floor management needed to be based on reliable information. It was decided that all production data should originate from the same source. This source was to be the MES database. With this concept agreed upon, the purpose of this project was achieved in two parts:

- Parameters that needed to be reported (or displayed) by the software were selected and verified for accuracy. Standard reports and dashboards were designed to be as user friendly and informative as possible. The meaning of these standardised reports and dashboards was carefully explained so that all parties using them will have a thorough, deep understanding of what is being communicated.
- Methods and hardware needed for interaction with the MES system were specified and developed. These differed broadly between departments and job descriptions. Upper management level employees were given tablet PCs (and smartphone interfaces) which they could use to access the MES interface. All employees can access

the MES interface through their networked computers both on and off company premises. Furthermore, MES sends out SMS alerts if machines go down throughout the day. Shop floor management and operators can view various displays over large screens placed throughout the shop floor and in various offices. These displays are customised for their purpose. Production floor screens, for example, show the production state overview (Figure C-2) while screens in the logistics areas would show the JIT delivery schedule.

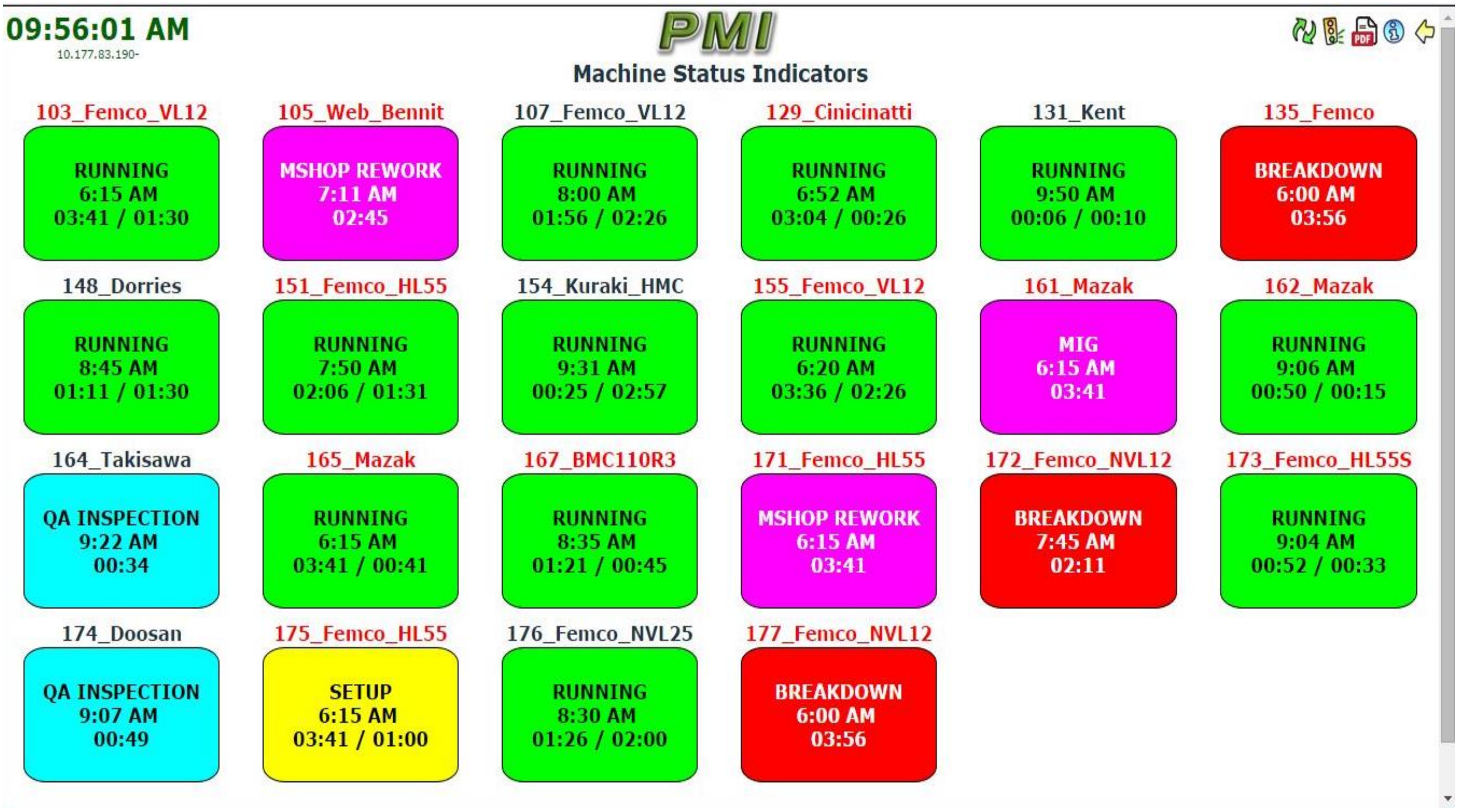


Figure C-2: Sample display - Production state overview.

Increased Functionality

This functionality was not part of the standard software design and had to be put forward for development. As per the four incomplete functionality issues identified, the following developments were carried out:

Real time clocking: All capturing of data had to be done in real time. To accommodate this the underlying MES database structure and input methods had to be updated so that operators capture the work they intend to start on, rather than what work they had just performed. This in turn gave a real time view of the current state of production, enabling support departments to react to issues immediately.

JIT delivery: The MES database was updated to account for the current state of material on the shop floor. Having a real time view of the material on the floor allows the yard to deliver work when and where it is needed, as opposed to flooding the shop with work in order "to be on the safe side".

Capturing quality: The function to capture quality-related activities was added to the MES system. This completed the picture in terms of giving visibility on what was happening to each part at any time.

Hardware and software upgrade: With the MES system adding additional strain to the IT infrastructure as it grew, functions were slowing down. The solution chosen was to upgrade the infrastructure rather than make the software less demanding:

- Database management software was upgraded
- Server processing speed was increased
- Terminal processing power was optimised

Roles and Responsibilities

The department specific roles were extended to include both working in the system as well as providing training. Each system user therefore became responsible for training those that could replace him. Shop floor operator training was particularly difficult because of the number of operators, the shift patterns that they worked, their level of computer literacy, and the extent of their function.

Continuous "train the trainer"-style training was necessary to maintain a satisfactory competence level. Continuous training to this extent also means users over time become system administrators who are able to troubleshoot basic issues and maintain data integrity.

Backup System

The backup system needed to ensure production continues, and data relating to production is not lost. The planning department developed a manual means to release work to production without having to go through either the scheduling tool or through MES. Operators were given a pen and paper based system to capture all the necessary machining information. While the system is inefficient, its simplicity ensures that no time is lost in the switch over.

Note that the key focus of the backup enabler was not to have an efficient way to work outside of MES, but rather to be able to get MES back online as quickly as possible when it goes down. This was done by giving MES system downtime a higher priority than any other IT-related tasks and ensuring backup hardware was always available on-site.