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The development of a value improvement model for repetitive processes

The Development of a Value Improvement Model for Repetitive Processes

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Abstract

For businesses to remain competitive in their marketplace they must continually look for different ways to satisfy the expectations of their customers and stakeholders as well as satisfy the needs of their employees and business partners. If they fail to do this then other businesses operating in the same marketplace will offer better value products and services to their customers resulting in a loss of revenue and the business may face the threat of closure. Overcoming this threat, looking to achieve competitive advantage, there are two distinct change options available.

Businesses can look externally, continually developing innovative new products perhaps adapting new technology winning the race to satisfy existing and potentially new customer expectations for better value products at minimal cost, &/or, they can look internally at their own processes with a view to continually improving these to be more efficient and effective maximising resource utilisation without devaluing the business in the eyes of their customers.

This thesis explores the second option, looking at how businesses can better align their resources and manage internal and external influencing factors to deliver sustainable competitive advantage through the use of a value improvement model for their repetitive processes. Multiple case studies are presented showing the development of the model through application and intervention in a practitioner environment. The linkage to the body of knowledge for systems thinking, strategy, lean and six-sigma is also made.

The main outcome of the thesis is the development of a useful, visual and systematic conceptual framework enabling managers to understand, assess and improve repetitive processes within their businesses through the taxonomy of value improvement models presented.

List of Publications[1] & Awards

Publications

1. Gibbons, P. M. (2006) Improving OEE: A Resource-Based View. In Antony, J. (Ed.) Conference Proceedings, Second International Conference on Six-Sigma, 5th-8th June 2006. Caledonian Business School, Glasgow Caledonian University.
2. Gibbons, P. M. (2006) 'Improving Overall Equipment Efficiency Using a Lean Six-Sigma Approach'. International Journal of Six-Sigma and Competitive Advantage, Vol. 2, No. 2, pp. 207-232.
3. Gibbons, P. M. (2008) Implementing 5S for Lean and Six-sigma Deployment: A Holistic Approach. In Antony, J. (Ed.) Conference Proceedings, Third International Conference on Six-Sigma, 15th-16th December 2008. Strathclyde University.
4. Gibbons, P. M. (2008) Introducing a Lean Resource Mapping Framework. In Antony, J. (Ed.) Conference Proceedings, First European Research Conference on Continuous Improvement & Lean Six-Sigma, 10th March 2008. Strathclyde University.
5. Gibbons, P. M. (2008) 'Introducing a Lean Resource Mapping Framework'. International Journal of Six-Sigma & Competitive Advantage, Vol. 4, No. 4, pp. 355-381.
6. Gibbons, P. M. (2009) Introducing a Lean Recruitment Framework for Manufacturing. In Nabhani , F. (Ed.) Conference Proceedings, 17th International Conference on Flexible Automation & Intelligent Manufacturing , 6th-8th July 2009. University of Teeside.
7. Gibbons, P. M. (2010) Incorporating Six-Sigma Thinking and Asset Management Strategy Performance Indicators into the Overall Equipment Effectiveness Measure (OEE). In Antony, J. (Ed.) Conference Proceedings, Second European Research Conference on Continuous Improvement & Lean Six-Sigma, 18-20th January 2010. Strathclyde University.
8. Gibbons, P. M. (2010) Introducing a Value Improvement Model for Repetitive Processes. INCOSE UK Annual Systems Engineering Conference. Oxfordshire, UK.

[1] Full papers -and where applicable conference presentations- are included in a CD located in the manuscript flyleaf.

9. Gibbons, P. M. & Burgess, S. C. (2010) 'Introducing OEE as a Measure of Lean Six-Sigma Capability'. International Journal of Lean Six-Sigma, Vol. 1, No. 2, pp.134-156.
10. Gibbons, P. M. & Kennedy, C. (2010) Delivering Stakeholder Value Through Sustainable Asset Management. IET Seminar, Asset Management in the New Economy: Sustainable Whole Life Decisions. IET London.
11. Gibbons, P. M. & Burgess, S. C. (2011) 'Lean Thinking: Developing a Theory of an Eighth Waste'. International Journal of Lean Six-Sigma, Vol. Forthcoming, No. TBC.
12. Gibbons, P. M. (2011) Introducing a Value Improvement Model for Repetitive Processes: an Airport Security Scanner Case Study Example. Ninth Annual International Conference on Systems Engineering Research. INCOSE, California.
13. Gibbons, P. M., Kennedy, C. & Burgess, S. C. (2011) 'Implementing a Value Improvement Model for Sustainable Asset Management'. International Journal of Quality & Reliability Management, Vol. Forthcoming, No. TBC.
14. Gibbons, P. M., Kennedy, C., Burgess, S. C. & Godfrey, P. (2011) Developing a Value Improvement Model for Repetitive Processes: Service Industry Case Study Examples. In Antony, J. (Ed.) Conference Proceedings, Third European Research Conference on Continuous Improvement & Lean Six-Sigma, 28th March 2011. Strathclyde University.
15. Gibbons, P. M. & Attwood, J. (2011) Developing a Value Improvement Model for an Environmentally Sustainable Airport. IQPC Infrastructure Asset Management Exchange. London.

Awards

1. Fraser Nash Best EngD Research Paper Award 2010.
2. International Journal of Lean Six-Sigma Best Paper Award 2010. Paper presented and published in the conference proceedings for the 2nd European Research Conference on Continuous Improvement & Lean Six-Sigma.

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Author's Declaration

I declare that the work in this dissertation was carried out in accordance with the requirements of the University's Regulations and Code of Practice for Research Degree Programmes and that it has not been submitted for any other academic award. Except where indicated by specific reference in the text, the work is the candidate's own work. Work done in collaboration with, or with the assistance of, others, is indicated as such. Any views expressed in the dissertation are those of the author.

SIGNED: DATE: 27th February 2012

Glossary & Acronyms

3DC	Three Day Car Research Project
3Es	Efficacy, Efficiency & Effectiveness
5S	Seiri, Seiton, Seiso, Seiketsu & Shitsuke
7Ps	Purpose, Perspective, People, Plant, Product, Process & Performance
ACC	Airport/Gatwick Control Centre
AMC	Asset Management Centre
AMD	Archway Metal Detector
ANOVA	Analysis of Variance
AR	Action Research
ASM	Airfield Stand Manager or Airport Senior Manager
ASO	Airport Security Officer
BTO	Build To Order
CA	Check→Act
CAA	Civil Aviation Authority
CAP168	Licensing of Aerodromes
CATWOE	Customers, Actors, Transformation Process, World View, Owner & Environmental Constraints
CMMS	Computerised Maintenance Management System (Maximo)
Cp	Process Capability Un-Centred
Cpk	Process Capability Centred
COO	Chief Operating Officer
CSER	Conference on Systems Engineering Research
DfT	Department for Transport
DMAIC	Define, Measure, Analyse, Improve, Control
DPMO	Defects Per Million Opportunities
EPSRC	Engineering & Physical Sciences Research Council
FMCG	Fast Moving, Consumer Goods
FMEA	Failure Mode & Effects Analysis
FM	Facilities Manager
FTL	Facilities Team Leader
HVAC	Heating, Ventilation & Air Conditioning
ICDP	International Car Distribution Programme
IMM	Injection Moulding Machine
IMRC	Innovative Manufacturing Research Centre
IMVP	International Motor Vehicle Project
INCOSE	International Council of Systems Engineering
IO	Industrial Organisation
ISO	International Organisation for Standardisation
JIT	Just in Time
KPI	Key Performance Indicator
LERC	Lean Enterprise Research Centre
LSL	Lower Specification Limit
LSS	Lean Six Sigma
Maximo	Computerised Maintenance Management System
MIT	Massachusetts Institute of Technology
MP	Maintenance Plans
MRP	Material Resource Planning
MTBF	Mean Time Between Failure
MTBS	Mean Time Between Scans

MTTF	Mean Time To Failure
MTTR	Mean Time To Repair
NNVA	Necessary But Non-Value Adding
NATS	National Air Traffic Services
NVA	Non-Value Adding
OAE	Overall Asset Effectiveness
OEE	Overall Equipment Efficiency/Effectiveness
OEM	Original Equipment Manufacturer
OPE	Overall Plant Efficiency
PAS 55	Publicly Available Specification for Asset Management
PDS	Product Design Specification
PEE	Production Equipment Effectiveness
PDR	Plan→Do→Review
PDCA	Plan→Do→Check→Act
Pp	Process Performance Un-Centred
Ppk	Process Performance Centred
P-value	Indicator of Data Normality/Indicator of Statistical Significance
QC	Quality Control
RACI	Responsible, Accountable, Consulted & Informed
RBV	Resource Based View (of the Firm)
Seiketsu	Standardise the Process
Seiri	Sort the Inputs to the Process
Seiso	Clean up the Inputs to the Process
Seiton	Straighten and Align Inputs to the Process
Shitsuke	Sustain the Required Level of Straightness for the Process Inputs
SIM	Stores & Inventory Management
SMED	Single Minute Exchange of Die
SOP	Standard Operating Procedure
SIPOC	Supplier, Input, Process, Output, Customer
SQR	Service Quality Rebate
SSI	Security Standing Instruction
SSM	Soft Systems Methodology
TEEP	Total Effectiveness Equipment Performance
TPIS	Total Productivity Improvement Visibility System
TPM	Total Productive Maintenance
TPS	Toyota Production System
TQM	Total Quality Management
TQMEX	Total Quality Management & Excellence Model
USL	Upper Specification Limit
VA	Value Adding
VIM	Value Improvement Model
VM	Vehicle Manufacturer
VSM	Value Stream Mapping

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Chapter 1: Introduction

1.1 Background to the Research

To remain competitive in their marketplace, businesses must continually look for different ways to satisfy the expectations of their customers and stakeholders as well as the needs of their employees and business partners. If they fail to do this, other businesses operating in the same marketplace will offer better value products and services to their customers resulting in a loss of revenue and the business may face the threat of closure.

There are two distinct change options available for businesses looking to achieve competitive advantage and overcome this threat. They can look externally, continually developing innovative new products perhaps adapting new technology to winning the race to satisfy existing and potential new customer expectations for better value products at minimal cost (Apple is a good example[2]). Businesses may also look internally at their own processes with a view to continually improving these to be more efficient and effective maximising resource utilisation without devaluing the business in the eyes of their customers (Toyota is a good example[3]).

This thesis explores the second option, by looking at how businesses can better align their resources and manage internal and external influencing factors to deliver sustainable competitive advantage through the application of systems thinking into real-world problems. The concept of a value improvement model for repetitive processes is introduced as a holistic model for understanding resource alignment taking into account the many influencing factors to delivering efficient & effective processes. Repetitive processes, rather than one-off processes, are

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[2] The introduction of the iPod and then continual product innovations has seen sales rise from $37 Billion in 2008 to $65 Billion in 2010 with net incomes also rising from $6Billion to $14 Billion in the same timeframe. See investor information for more details: http://www.apple.com/investor/

[3] The Toyota Production System is based around the elimination of waste in the eyes of the customer. http://www.toyota-global.com/company/vision_philosophy/toyota_production_system/
This approach to internal optimisation (as well as external influences such as quality of product) has seen Toyota grow to become the largest automotive manufacturer in the world. The author feels it is worth mentioning the recent problems reported in the media with Toyota vehicles. Recently a problem with Toyota vehicles was claimed to be an electronic design fault with Toyota recalling 8 million vehicles in the USA alone. However an investigation by NASA found there was nothing wrong with the electronics *"NASA found no evidence that a malfunction in electronics caused large unintended accelerations,"* and the problem was probably operator error *"pedal misapplication"*. See the full report from the Department of Transport and a short article from NASA for more details:
http://www.nhtsa.gov/staticfiles/nvs/pdf/NHTSA-UA_report.pdf
http://www.nasa.gov/topics/nasalife/features/nesc-toyota-study.html.

purposely chosen to allow for the measurement of key outputs of the process to be captured over time. The Author argues this will allow for value improvements to be realised through understanding the impact of any interventions made therefore developing mature and sustainable process outcomes. With a one-off process there is not necessarily the same opportunity to feedback and understand the outcomes to realise value improvements.

Developing the value improvement model, six-sigma and lean are introduced as two well established methodologies proven to deliver tangible improvements to businesses through process variation reduction and better resource utilisation. The six-sigma: Define→ Measure→ Analyse→ Improve→ Control (DMAIC) process improvement structure is introduced as a useful framework for structuring value improvement. Complementing DMAIC, the lean focus on understanding customer expectations (what is value adding in their eyes) and driving improvements back through the business to ensure these expectations are met with minimum resources employed is seen as a useful philosophy for achieving value improvement[4].

However, the literature review also identifies potential weaknesses with the six-sigma & lean conceptual frameworks, including problems with implementation, flexibility, responsiveness, the dehumanising approach, contingency and an overall lack of holistic thinking which leads to unsustainable improvements and subsequently negative consequences to the business.

Bringing together a portfolio of individual developments to the six-sigma and lean conceptual frameworks, and applying systems thinking to overcome extant criticisms of lean and six-sigma, the concept of a value improvement model for repetitive processes is introduced. Arguing competitive advantage can be realised through different amalgams of productive and strategic resources, the value improvement model conceptual framework focuses on aligning resource bundles and understanding internal and external influencing factors creating efficacious, efficient and effective processes by applying lean thinking and six-sigma tools and techniques more holistically.

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[4] Lean and the links with the previously discussed Toyota Production Systems will be reviewed in more detail in Chapter 3.

Building on the six-sigma & lean conceptual frameworks, the argument is made that the value improvement model is complimentary to these extant process improvement methodologies, providing a visual and holistic framework to facilitate sustainable business improvements. For example, the value improvement model provides a visual framework to better understand the three main direct inputs to a process including the resource bundles, voice of the customer and process information.

Complimenting this specific understanding of the inputs is the need to measure the process performance against efficacy, efficiency and effectiveness matched to the customer requirements. Creating a continuous value improvement cycle, the approach can be used to visualise the link between the six-sigma DMAIC and Deming, Plan→Do→Check→Act (PDCA) processes in particular the two feedback loops of 'change improve' and 'change act' to the process inputs previously introduced as resource bundles, customer needs and process information.

Applying systems thinking principles, the approach also looks to better understand the internal and external influencing factors explicitly focusing on their potential negative and positive impact upon the repetitive process under review. Multiple case studies are presented showing the development of the value improvement model through the application in a practitioner environment and the linkage to the body of knowledge for systems thinking, six-sigma and lean is made.

The main outcome of this thesis is therefore the development of a visual and systematic conceptual framework enabling managers to understand, assess and improve repetitive processes within their businesses. The case study examples presented show the operationalised conceptual framework and the application and usefulness for both specific process improvement activities and for setting-up value improvement management cycles in both manufacturing & service industry environments.

1.2 Research Hypothesis & Questions

Developing a meaningful research hypothesis, the Author builds on opportunities to explore individual elements of the lean and six sigma framework previously found to be useful in industry based interventions[5]. Also with the knowledge that there is opportunity to further develop these tools and techniques both individually and holistically by applying systems thinking to develop a value improvement model where the whole is greater than the sum of the individual parts. Therefore, this thesis is structured around both theoretical and a practical investigations developing & testing concepts with the overall objective of validating the findings against the following research hypothesis:

Systems Thinking, combined with developments to both the Six-Sigma: Define→Measure→Analyse→Improve→Control (DMAIC) framework and the Lean customer focused value philosophy, can be used to develop a value improvement model for repetitive processes useful to both manufacturing and service industry applications.

Operationalising the hypothesis, this thesis is split in two parts with the first part developing individual elements of the lean and six sigma frameworks and the second part merging the individual elements into a holistic value improvement model which is further developed as business intervention opportunities are identified. Developing specific research objectives and providing structure to the thesis, the following is a list of the research questions to be answered in the development of a value improvement model for repetitive processes:

R1. Can 5S be applied as a philosophy for sustained business improvements or is it just a tool for housekeeping in factories specifically on the shop floor?

R2. Can the lean measure of overall equipment effectiveness (OEE) be used within the six-sigma DMAIC improvement process?

R3. Can the measure of OEE be expanded to incorporate asset management performance indicators and a level of six-sigma capability giving a holistic indicator of lean six-sigma capability?

R4. Will a new lean tool introduced as a lean resource mapping framework complement the extant lean conceptual framework through the introduction of an 8th waste classified as polarisation?

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5 The author has worked as a practitioner in industry for over twenty-five years and has first-hand experience of the successes and failures when using these tools and techniques triggering a personal interest in their further development also with a feeling that they could combined together to develop a better approach to process improvement.

R5. *Can the DMAIC, 5S, OEE, lean resource mapping framework and the lean recruitment framework tools be incorporated into the development of a single value improvement model for repetitive processes in manufacturing?*

R6. *Can the manufacturing value improvement model be adapted for use in a service industry environment?*

R7. *Can the value improvement model be further developed to a more generic level moving away from the specific lean tools such as 5S and OEE by applying systems thinking?*

R8. *Can the generic value improvement model be further developed to incorporate a current state map and future state map of the repetitive process under review?*

1.3 Thesis Structure

Presenting evidence of the investigation and providing discussion on its usefulness, this thesis is based around the following structure with Chapters 2-6 focused on individual elements of lean and six-sigma development and Chapters 7-12 focused on developing a holistic value improvement model for repetitive processes:

Chapter 2: Research Methodology discusses how the thesis is developed around a journey of theory development using a research methodology incorporating multiple case studies through the action research process of planning, observing and reflecting summarised as an action case study research design. The research methodology chosen is introduced including a brief review of the other options and the implications of this approach including ethics and validity. The action case study approach is discussed including the use of ethnography, surveys & semi-structured interviews before the final research strategy and design is presented.

Chapter 3: Review of Six-Sigma & Lean encompasses a captious & taxonomic literature review of the six-sigma & lean conceptual frameworks. Six-sigma is reviewed and a focus is made on the DMAIC framework suitability for achieving value improvement. Lean is also reviewed and the suitability to understand and maximise value in repetitive processes is made. Understanding potential weaknesses with the lean conceptual framework, an example is provided from the automotive industry where lean has been applied to the vehicle assembly plants and material is delivered Just-in-Time (JIT) to the assembly areas and vehicles are assembled with minimum waste. However, the finished products are then stored in large car parks & dockyards[6] until a customer order is received for that particular model.

Chapter 4: Review of 5S encompasses a taxonomic review of the 5S lean philosophy building on the preceding six sigma & lean literature reviews. 5S is introduced as a system for workplace and process organisation and the argument is made that sustainable business improvement using lean and six-sigma techniques can be achieved through the successful application of 5S. This Chapter argues a stable process achieved through 5S is the foundation for continuous improvement to any repetitive process. Developing a conceptual framework, a case study based around surveys/audits and semi-structured interviews is discussed before a sustainable business improvement model is presented.

Chapter 5: Improved Overall Equipment Effectiveness Measure complimenting the 5S system, the lean toolbox measure of overall equipment effectiveness (OEE) is introduced as a holistic measure of lean and six-sigma process capability. The link with lean and six-sigma philosophies is also made through the use of OEE as a measure in the six-sigma management DMAIC improvement cycle and a case study example is presented to illustrate the usefulness of this approach. Also linking back to Chapter 4, first pass improvements to the process are achieved by applying 5S principles.

A second case study is presented arguing how OEE can be further developed to incorporate other indicators of asset and process performance including Mean-Time-To-Repair (MTTR), Mean-Time-To-Failure (MTTF) & Mean-Time-Between-Failures (MTBF). Further developing the OEE measure, this case study also discusses how an indicator of six-sigma capability can be included in the OEE measurement framework.

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[6] The author carried out fieldwork study at Royal Portbury Docks in 2005 and observed up to 100, 000 unsold vehicles being stored in the dockyard at this time. With the average vehicle valued at £15 000, an estimate for the stock would be in the region of £1.5 Billion worth of unsold vehicles waiting for a customer. This problem is discussed in Chapter 3 where more detail is provided on lean and the problems within the automotive industry.

Chapter 6: Developing a Lean Resource Mapping Framework out of a need to resolve a specific problem in the workplace identified through using OEE as a measure, this Chapter introduces the concept of an eighth lean waste classified as polarisation –the disconnectivity and potentially wasted opportunities extant between people, plant, processes and products. Operationalising the conceptual framework a lean resource mapping practitioner framework is presented and the usefulness discussed against two manufacturing-based case study examples.

Chapter 7: A Value Improvement Model for Repetitive Processes: Application to Manufacturing introduces the development of the value improvement model and links to the preceding Chapters bringing the individual elements together into a single conceptual framework. A case study is presented arguing how the value improvement model can be operationalised and applied to a manufacturing environment using OEE as a measure.

Chapter 8: Applying the Value Improvement Model to the Service Industry introduces a case study based around a service industry Airport security scanner process arguing the manufacturing biased value improvement model can be further developed and therefore be applicable to both manufacturing and service industry environments.

Chapter 9: Applying the Value Improvement Model to Engineering Operations Applying Systems Thinking introduces a case study based around improving the effectiveness of an asset management repetitive process in an Airport engineering team. This Chapter discusses the use of systems thinking and shows how the -Customer, Actors, Transformation, Worldview, Owner & Environment- (CATWOE) soft systems approach can be used to further develop the value improvement model into a generic framework applicable to any repetitive process.

Chapter 10: Applying the Value Improvement Model to Management introduces a further development to the value improvement model arguing its usefulness presented in a case study based around setting up a management value improvement cycle on an Inter-Terminal Shuttle transportation system within an Airport.

Chapter 11: Other Value Improvement Model Applications shows how the value improvement model can be applied to a stores and inventory management system and to the delivery of an environmental strategy for a sustainable Airport. The purpose of introducing these other applications of the value improvement model is to illustrate how generic the final version of the model has become.

Chapter 12: Conclusions summarising the key points from the investigation and revisiting the hypothesis. The contributions to the body of knowledge are presented and future research opportunities are identified to further develop the value improvement model for repetitive processes.

Appendix A: Developing a Lean Recruitment Framework through the action research approach and supporting the lean resource mapping framework introduced in Chapter 6, this Appendix introduces a useful new lean tool focused on streamlining the recruitment process. Using case study examples, the argument is made that a balanced approach to both controlled divergent -knowledge accumulation- and controlled convergent -decision making- will streamline the overall recruitment process focusing on what is value adding in the eyes of the hiring manager. The lean recruitment framework was developed out of the need to ensure personnel employed match the requirements of the hiring manager using a Pugh Matrix to streamline the selection process. The argument is also made that the lean recruitment system can also be used to assess existing employee capability to match the hiring manager requirements.

Appendix B: Other Achievements & Activities summarises other relevant and noteworthy achievements through the development of the thesis including practitioner tools and techniques developed, lectures and training delivered, presentations to research groups and the peer reviewing of International Academic Journals.

Appendix C: Shuttle Individual Car Pareto Analysis shows the full Pareto analysis of the individual Car alarms discussed in Chapter 10.

Appendix D: Research Reflections discusses the outcomes of the research understanding the challenges and value improvement model strengths, limitations and business value & impact.

1.4 Summary

This Chapter of the thesis has introduced the background to the research and presented the research hypothesis and research questions to be answered in this investigation. The next section of this thesis will set out the framework and methodology for developing and validating a value improvement model for repetitive processes.

Chapter 2: Research Methodology

2.1 Introduction

Before the main literature review is completed it is important to understand the framework and methodology for this research investigation in particular the research strategy and design which will influence the validity and reliability of any research findings.

2.2 Research Strategy

Gustavsen (2003) argues research positions must be formed to meet the specific conditions under which research is to operate and topics like ontology and epistemology can help provide some ideas on how this can be met. Bryman (2001) concurs, suggesting a research strategy is based on the relationship between theory and research as well as the epistemological and ontological issues present. Bryman and Bell (2003) suggest at a fundamental level, the ways in which these issues relate defines whether the research strategy will be quantitative or qualitative or possibly a combination of both (*cf.* Table 1).

Category	Quantitative	Qualitative
Principle orientation to the role of theory in relation to research	Deductive; testing theory	Inductive; generation of theory
Epistemological orientation	Natural science model, in particular positivism	Interpretivism
Ontological orientation	Objectivism	Constructionism

Table 1: Fundamental Differences Between Research Strategies (Bryman & Bell, 2003)

2.2.1 Theory

Collis & Hussey (2003) classify theory as the logic of research which can either be deductive or inductive. Detailing further, Collis & Hussey (2003) describe deductive research as *"a study in which a conceptual and theoretical structure is developed and then tested by empirical observation, thus particular instances are deduced from general inferences";* therefore deductive theory guides research. Conversely, Collis & Hussey (2003) describe inductive research as *"a study in which theory is developed from the observation of empirical reality; thus general inferences are induced from particular instances*". Inductive research is antithetical to deductive research and therefore, theory is an outcome of inductive research.

2.2.2 Ontology

Johnson & Duberley (2000) describe ontology as a branch of metaphysics that deals with the essence of phenomena and the nature of existence; it is the theory of knowledge and asks whether something is real or illusionary. Easterby-Smith *et al.* (2002) suggest ontology is simply the assumptions we make about the nature of reality.

Developing taxonomic definitions, Collis and Hussey (2003) argue ontological assumptions are dependent on whether you (the researcher) consider the world to be objective and external to the researcher, or is socially constructed and only understood by examining the perceptions of the human actors. Bryman (2001) introduces two disparate ontological perspectives commonly discussed in philosophy literature. Objectivism is introduced as, *"an ontological position that asserts that social phenomena and their meanings have an existence that is independent of social actors"*, and constructionism is, *"an ontological position that asserts that social phenomena and their meanings are continually being accomplished by social actors"*.

Similarly, Johnson and Duberley (2000) argue a subjectivist ontology assumes that what we take to be external social and natural reality is merely a creation of our consciousness and cognitions: *"reality is a projection of our cognitive structures with no independent status"*. Johnson and Duberley (2000) also introduce realism as another ontological position where *"social and natural reality exist independently of our cognitive structures: an extra-mental reality exists whether or not human beings can actually gain cognitive access to it"*.

2.2.3 Epistemology

Easterby-Smith *et al.* (2002) introduce epistemology as a "general set of assumptions about the best ways of inquiring into the nature of the world". Similarly, Benton & Craib (2001) argue epistemology is the theory of knowledge and suggest two main standpoints can be taken, positivism and interpretivism. Detailing further, Bryman & Bell (2003) propose positivism is *"an epistemological position that advocates the application of the methods of the natural sciences to the study of social reality and beyond"* and interpretivism is a *"contrasting epistemology to positivism"* and the research strategy adopted should *"respect the difference between people and* *the objects of the natural sciences and it therefore requires the social scientist to grasp the subjective meaning of social action".* Bryman (2001) classifies phenomenology as a contrasting epistemology to positivism and categorises it under the interpretivist epistemology as anti-positivist. Potter (2000) criticises the positivist standpoint arguing a focus on producing precise and measurable laws in an objective manner limits the potential to explain social phenomena.

2.2.4 Research Strategy for this Study

Typically the field of Production and Operations Management (POM) has utilised a natural science model as the approach for carrying out research (Bryman and Bell, 2003). The evidential lack of epistemology and ontology discussions in the prominent POM academic journals leads the researcher to understand that traditionally a positivist epistemology, objectivist ontology and quantitative strategy, testing theory by deduction, is accepted as normal unless otherwise stated (see for example: Westbrook, 1994; Arlbjorn and Halldorsson, 2001; Coughlan and Coghlan, 2002; Hines *et al.*, 2002; Mills *et al.*, 2003, for contrasting examples) [7].

A short research project carried out by the author (Gibbons, 2004a) investigating the research strategies employed by automotive industry researchers on a 3DayCar project (3DayCar, 2001) confirmed this assumption and the findings showed quantitative, positivist and objectivist research strategies were mainly employed and ontological and epistemological positions were not discussed in detail, if at all (Howard *et al.*, 2001; Miemczyk *et al.*, 2002; Miemczyk and Lawson, 2002; Holweg and Miemczyk, 2002; 2003; Howard *et al.*, 2003; Howard and Holweg, 2004; Howard *et al.*, 2004; Miemczyk and Holweg, 2004).

Relating these research strategy decision problems back to the study in question draws the author to briefly re-visit the research aims and questions specifically to facilitate the formation of appropriate research positions. As Gustavsen (2003) suggests, "*research positions must be formed to meet the specific conditions under which research is to operate".*

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[7] This is based on a literature review searching discussions relating to 'epistemology' and 'ontology' within the leading academic journals referenced in the main literature review of this study including: The International Journal of Production and Operations Management; Production and Operations Management; International Journal of Quality and Reliability Management; International Journal of Lean Six Sigma; International Journal of Logistics Management; Journal of Operations Management; International Journal of Six-Sigma and Competitive Advantage.

To develop the lean & six-sigma conceptual frameworks further, the ontology standpoint of objectivism will be taken viewing the conceptual framework presented as external to the influences of social actors, contrary to the constructionist standpoint (Johnson and Duberley, 2000; Bryman, 2001; Easterby-Smith *et al.*, 2002; Collis and Hussey, 2003; Bryman and Bell, 2003). The argument is made that an objective standpoint is necessary as the research questions suggest a deductive approach to theory where *"particular instances are deduced from general inferences"* as suggested by Collis & Hussey (2003) fitting the ontology-objectivist-deductive paradigm presented by Bryman and Bell (2003).

For the establishment of an epistemological standpoint the decision is much more difficult. Following Bryman and Bell's (2003) research strategy framework presented in Table 1, the epistemology standpoint for this study should be positivist, using a natural science model to make generalisable laws through empirical observation. However, previous research activities carried out by the author have adopted an action research design which from an epistemology standpoint is seen as antithetical to the positivist standpoint taking a qualitative and interpretivist approach to knowledge creation (Eden and Huxham, 1996).

The disparity between positivism and action research is best discussed by direct comparison as suggested by (Coughlan and Coghlan, 2002).

	Positivist Science	**Action Research**	**This Research Project**
Aim of research	Universal knowledge. Theory building and testing	Knowledge in action. Theory building and testing in action	Further development of an existing theory in practice
Type of knowledge required	Universal, Covering law	Particular. Situational. Praxis	Universal, covering law not situational
Nature of data validation	Context free. Logic, measurement. Consistency of prediction and control	Contextual embedded. Experimental	Context free
Researcher's role	Observer	Actor. Agent of change	Facilitator
Researchers relationship to setting	Detached neutral	Immersed	Participant and observer

Table 2: Comparison of Positivism and Action Research to this Study
(adapted from Coughlan & Coglan, 2002)

Table 2 shows Coughlan & Coghlan's (2002) direct comparison of key aspects of a research project in the context of a positivist scientific approach, an action research approach, and finally the approach to be adopted during this research project. The tabulated comparison shows the approach taken within this research project has similarities and disparities with both positivism and action research suggesting that neither a positivist science epistemology or an action research design are fully applicable to this study. Therefore an alternative overall research design should be identified in parallel to the identification of an epistemological standpoint.

2.3 Research Design

Bryman & Bell (2003) define a research design as the framework for collecting and analysing data. The research design differs from research methods as these are techniques used specifically for the collection of data.

2.3.1 Research Design Options

Bryman and Bell (2003) suggest five prominent research designs - experimental design; cross-sectional design; longitudinal design; case study design and comparative design. Additionally, action research and ethnography will be reviewed as to their suitability as a research design for this project based on other work completed by the author (2004a; 2004b).

Experimental Design

Collis and Hussey (2003) describe an experimental design as a scientific positivist methodology comprising an experiment that is either being conducted in a laboratory or a natural setting, and both in a systematic way. Bowling (1997) details the experiment as a situation where an independent variable is carefully manipulated by the researcher under known, tightly defined and controlled conditions. The resultant effect, the dependent variable, is then observed. Lewis-Beck (1993) distinguishes the difference between experimental and non-experimental methods with the experimentalists manipulating variables suspected of producing an effect, while non-experimentalists observe them.

Cross-Sectional Design

According to Collis and Hussey (2003), cross sectional studies are a positivistic methodology taking a snap-shot of an on-going situation to investigate economic characteristics of large numbers of people or organisations. Burton (2000) details the method further explaining that data collected from at least two groups at one point in time is compared and the differing extents are analysed. Easterby-Smith et al (2002) argue that cross-sectional designs are useful for economically describing features of large numbers of people or organizations but do not or find it hard to explain why the observed patterns are there.

Longitudinal Design

Collis and Hussey (2003) suggest that a longitudinal study is usually, but not always, associated with a positivist methodology. Menard (1991) describes the approach as one that collects data for two or more distinct time periods with the subjects being the same or comparable from one period to the next. Pettigrew (1990) argues that longitudinal studies are important in understanding the way organizations change and the results will provide data on the mechanisms and processes that are influential to change.

Comparative Design

Bryman and Bell (2003) argue that a comparative research design is useful to uncover contrasting findings between two or more cases.

Case Study Design

According to Collis and Hussey (2003) a case study is usually associated with the extensive examination of a phenomenon of interest, probably a form of exploratory research, which is classified under the umbrella of a phenomenological methodology. Bryman (2001) classes phenomenology as a contrasting epistemology to positivism and categorises it under the interpretivist epistemology as anti-positivist.

Yin (1994) describes a case study as an *"empirical enquiry that investigates a contemporary phenomena in context; when the boundaries between the phenomenon and the context are not clearly evident, multiple sources of evidence are used"*. Scapens (1990) suggests that there are four additional case study types to those suggested by Collis and Hussey: descriptive, illustrative, experimental and explanatory. Blaxter *et al.* (2001) argue the case study is *"in many ways, ideally suited to the needs and resources of the small-scale researcher"*.

Action Research

The term action research (AR) was originally coined by Lewin (1946) who saw the process of enquiry as forming 'a cycle of planning, observing and reflecting' (Collis and Hussey, 2003). Rappoport (1970) explains that *"AR aims to contribute both to the practical concerns of people in an immediate problematic situation and to* *the goals of social science by joint collaboration within a mutually accepted ethical framework"*. Easterby-Smith *et al.* (2002); Reason & Bradley (2000); Reason & Rowan (1981); and Collis & Hussey (2003) highlight this 'collaboration' between researcher and researched as important when developing shared understandings. Brown (2009) suggests another duality when taking an action research approach, it allows the researcher to make a 'real-time' contribution to the research setting in parallel to matching the expected academic rigour.

There is considerable debate over the nature of the AR methodology (Collis and Hussey, 2003), but as Robson (1993) argues, *"improvement and involvement seem central to all users of the term"*. However, this closeness and focus on involvement and improvement has led to some criticism that some projects are closer to consultancy or journalism (Gummesson, 1991) or established always and explicitly to improve practice (Griffiths, 1998) thus not solely incorporating research as the main objective.

Ethnography

Dicks and Mason (2005) suggest ethnography translates from Greek with *"Ethnos"'* meaning "foreigner" and *"graphos"* meaning writing, thus *"Ethnography"* means writing about foreigners. This translation fits in with the anthropology carried out by Victorian ethnographers who visited foreign lands to gain access to local cultures and later write up their findings (Bryman, 2001).

Willis and Trondman (2000) argue that the first ethnographer was Herodotus and the first ethnography written was 'The History' (Herodotus, 1987). In this work Herodotus presents a description of his work *"So far it is my eyes, my judgement, and my searching that speaks these words to you"*. This overall 'experience' is a key aspect of ethnography (Willis and Trondman, 2000). Bryman and Bell (2003) suggest organisational ethnography as an adaptation of ethnography by business researchers interested in the study of organizational settings. Rosen (1991) argues this distinction is due to the social relations linked to goal directed activities that are not present in other areas of social life.

Van Maanen (1979) suggests the principle aim of organisational ethnography is to 'uncover and explicate the ways in which people in particular work settings come to understand, account for, take action, and otherwise manage their day-to-day situation'. Bate (1997) presents a warning to potential ethnographers arguing that there are now more people writing about ethnography than there are actually doing it. This *"jet-plane ethnography"*, as he describes it, consists of a series of *"flying visits"* producing *"quick descriptions"* rather than the *"prolonged contact in the field"* that is needed to collect *"thick descriptions"*. Bryman and Bell (2003) suggest examples of organisational ethnography based on participant observation in factories (Roy, 1958), (Lupton, 1963) and (Beynon, 1975). Deldridge (1995) presents a more recent account of ethnography in 'Surviving JIT: Control and Resistance in a Japanese Transplant'. The paper is based on an ethnographic study in a Japanese owned consumer electronics plant sited in England.

2.3.2 Research Design for this Research Project

The approach to be adopted for this study will not be totally positivistic or use action research as an overall research design but both positivism and action research have attributes that must be included in the overall research strategy. Therefore an alternative approach or hybrid of the two must be identified. The alternative research designs discussed in the previous section must now be critically reviewed as to their suitability to the in-context research aims and questions; all in the development of a suitable research design for this study.

The nature of the research for this project -looking to develop the theoretical frameworks informing the lean & six-sigma concepts- would suggest an experimental design would not be totally suitable as the purpose is not to manipulate a variable, to see the effects; as would be the case for testing the effects of lean & six-sigma against a variable such as plant performance.

Similarly a cross-sectional design is not totally applicable as the research aim is to further develop an extant theory and not to compare the implementation of lean & six-sigma in two separate settings, at a given point in time.

A longitudinal research design would also not be totally applicable as a study of how an implementation of the lean & six-sigma frameworks may have changed over time is not relevant. However, the longitudinal approach could be useful to re-visit previous research projects, especially those where the researcher has taken an interventionist approach such as action research.

Comparative research design is very similar to the cross-sectional research design and useful for identifying inferences between two separate cases.

Ethnography research designs are useful for observing change within organizations, looking for inferences taken from observation in the development of new theories (Roy, 1958; Lupton, 1963; Beynon, 1975; Deldridge, 1995). In the context of this research project ethnography is not totally suitable as the researcher will mainly take a facilitatory role in-situ within a firm with the objective of collecting objective process specific data and some subjective observatory data.

The final two research designs, case study and action research both provide useful elements in the formulation of a suitable framework and therefore perhaps a hybrid approach is appropriate as has been previously suggested by Vidgen & Braa (1997) and Braa & Vidgen (1999). Vidgen and Braa (1997) introduce an *action case* research design as a hybrid of action research and case study research to be used when conducting in-context research (*cf.*, Figure 1).

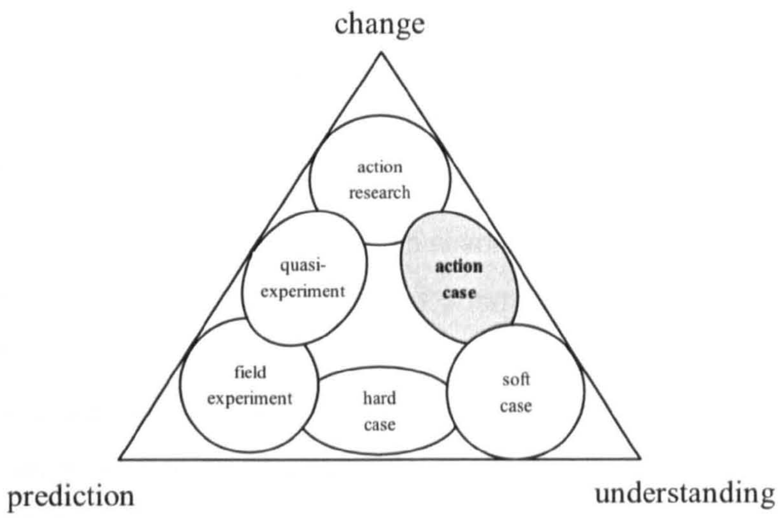

Figure 1: Research Method Location (Vidgen & Braa, 1997)

Although originally intended for use within the information systems field of operations management research, the suitability to this study is worth further investigation and perhaps other lean concept development work has unknowingly utilised an action case approach (Hines and Rich, 1997; Hines *et al.*, 2000; 2002; Womack and Jones, 1994; 1996b; 2005a; 2005b). Braa and Vidgen (1999) make a useful argument justifying the more general use of action case design for doctoral students:

"The action case method is particularly well-suited to situations where full action research is not possible or is not appropriate. For example, action case

can be used by new researchers, such as doctoral students, who wish to gain experience on in-context research on a small-scale..."

Braa and Vidgen (1999) argue the action case approach encompasses both positivistic reductionism and interpretivist understanding, both of which cause intervention at some level when carrying out in-context research; thus suggesting the researcher can never totally be an *"objective outsider or a subjective insider"*.

		Hard case study	Soft case study	Action research	Action case	Field experiment	Quasi-field experiment	This Study
Research Outcome	Change (intervention)	Unintended	Unintended	Intended, large-scale	Intended, small to medium scale	Intended, small scale	Intended, small scale	Small to medium
	Prediction (reduction)	Medium	Low	Low	Low	High	Medium	Low
	Understanding (interpretation)	Medium	High	Low to medium	Medium	Low	Low to medium	Medium
Research Characteristics	Duration	Any	Any	Long	Short to medium	Short	Medium	Short
	Time orientation	Contemporary	Historic and contemporary	Building future	Contemporary and building future	Contemporary	Contemporary and building future	Contempor ary
	Participation	Low	Low	High	Medium	High	Medium	Medium

Table 3: Research Method Characteristics (Braa & Vidgen, 1999)

Table 3 shows the differing research characteristics in relation to the possible research designs applicable to this study as presented by Braa and Vidgen (1999). The use of the tabular criteria as a comparator for alternate research designs identifies the action case design as a near exact match to the anticipated approach to be adopted during this study. For example, for both this study and the action case design, the prediction of research outcome is low for both and the understanding levels are both matched at a medium level.

However, the match in research outcomes in not exact as the research outcomes for this project suggest the level of change expected will be small to medium but not intended as with soft and hard case study designs; antithetical to action research design which would be intended to change at a large scale. Although there are minor differences between the action case design and the ideal approach for this project, the action case approach will be adopted as the overall research design for this study.

Operationalising the research framework, Braa and Vidgen (1999) provide a useful table comprising of important factors to be considered when conducting action case projects. Table 4 shows the completed research characteristics table for this study. As has been identified through the completion of the characteristics of research design check sheet (Braa and Vidgen, 1999), a suitable methodology for data collection has not yet been formally presented and therefore to complete the action case research design the data collection methodology must now be discussed.

Factor	Attribute	Action case concern	Appropriateness to this research project
Suitability	Research design	Have a framework of ideas and a methodology been declared?	A conceptual framework has been presented but the data collection methodology has not yet been discussed.
	Research skills	Does the researcher have the skills and experience to make an intervention?	The researcher has worker as a senior manager in the manufacturing industry and has over twenty five years of experience in the field to be studied. The researcher has also used an action research type approach in two previous MSc level research projects.
Interpretation	Richness	Is the context of the research rich enough to provide understanding?	The organisations where the research will be carried out offer the opportunity to map the resources; people, plant, processes and products from raw material being delivered to the finished product delivery to the customer.
	Focus	Is the research question sufficiently focused?	The research questions focus on the development of a value improvement model for repetitive processes.
Intervention	Scale	Is the scale of the subject for research manageable?	The researcher is matching the requirements of the business to those of the research questions through this action case study approach.
	Participation style	What level of participation can be expected from the organization members?	The Managing Directors of the organisations to be studied are fully supportive of the researcher and are happy for employees to be involved in the data collection activities.
	Critical impact	Is a critical approach required?	A critical approach is not necessary in this case.
Practicability	Economics	Is sufficient financial support and research time available?	The organisations are sponsoring the researcher in the way of travel expenditure and accommodation payment for taught modules and attendance at conferences.
	Access	Can access be negotiated with stakeholders (e.g. users, managers, developers, customers, business partners?)	The Managing Directors of the organisations are fully supportive of the research especially as an outcome will identify areas for improvement within the business.
	Politics	Does the research conflict with the organizations politics? Is there sufficient backing for the action and case components?	The researcher has spent two week blocks in the organisations involved carrying out familiarisation exercises. The indications from this are that the employees are very interested in the research project and are enthusiastic to be involved in the data collection activities.
	Control	Can the research project be controlled?	The data collection will be controlled by an agreed schedule put together by the researcher and the Industrial Supervisors.

Table 4: Characteristics of Research Design
(adapted from Braa & Vidgen, 1999)

Data collection methods to be used include: observation of work practices; one-to-one interviews with employees; group discussions; documentation analysis & participation in company activities working in engineering and operations management roles.

2.3.3 Validity and Reliability of Research[8]

Bryman & Bell (2003) put forward validity and reliability as two important criteria for establishing and assessing the quality of research. Although they were originally associated with quantitative research, Mason (1994) suggests the meanings are the same for both quantitative and qualitative approaches. However, LeCompte & Goetz (1982) and Kirk & Miller (1986) argue the meanings are not the same as those for quantitative research and alternative definitions should be used.

This also concurs with Lincoln & Guba (1985) and Guba & Lincoln (1994) who suggest alternative criteria for assessing qualitative research: trustworthiness and authenticity.

Trustworthiness is further sub-divided into: credibility, transferability, dependability and confirmability; all of which parallel the different internal and external aspects of reliability and validity in quantitative research in some way or another (Bryman, 2001). Therefore it is important to take into account the different definitions of validity and reliability in relation to quantitative and qualitative research when carrying out a critical review and the judgement criteria proposed by LeCompte & Goetz (1982) internal reliability; external reliability; internal validity and external validity will be discussed further in relation to ethnography and action research.

Ethnography and action research (AR) are chosen as two qualitative research designs that are encompassed into the action case research design being used for this project and the discussion is seen as important in the development of reliable and valid research.

Internal Validity

LeCompte and Goetz (1982) argue that internal validity is based on the relationship between the researchers' observations and the theoretical ideas they develop; if there is a good relationship between the two then the internal validity is high and vice-versa. Relating this to ethnography, Metcalf (2002) presents a warning, *"if they lie, we lie"*, thus if the observation is inaccurate due to the observed lying then the internal validity will be poor.

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[8] This section is based in part on an essay submitted as a taught module on qualitative research methods which received a distinction level grade (see, Gibbons, 2004c).

Ethnographers will argue that the *"prolonged time spent in the field"* (Bate, 1997), will reduce the chance of the observed continually deceiving the researcher. However, this prolonged time spent in the field also creates another problem for the internal validity of the research. Bryman and Bell (2003) suggest that there is a chance of *"going native"* where the ethnographer becomes so wrapped up in getting close to the people being observed that they themselves take up the world view of the people they are studying and thus lose sight of the their position as a researcher (Beynon, 1975).

Wolcott (1995) suggests *"micro-ethnography"* as an alternative for the small scale researcher who will not be able to spend a prolonged time in the field. Fitting between the 'jet-plane ethnographer' and the ethnographer who 'goes native', the micro ethnographer spends a shorter period of time (e.g. between 1 to 3 months) focusing on one particular aspect of an organizations culture such as how the organization has implemented lean.

Relating this to internal validity, the micro-ethnographer would achieve higher levels than that of the 'jet-plane ethnographer' but would not achieve the same level as the ethnographer who 'spends a prolonged time in the field' (ignoring the possibility of the observed deceiving the ethnographer or the ethnographer 'going native').

An example of organizational ethnography presented by Deldridge (1995) is based on a four-week period of overt participant observation supported with documentary analysis. The short period of observation suggests a 'jet-plane' ethnography (Bate, 1997) resulting in quick descriptions rather than thick descriptions. These quick descriptions come from 'fly on the wall' observations rather than in-depth understandings of the observed. The internal validity of Deldridge's research is therefore questionable due to the short time spent at the factory.

For AR the internal validity can literally be confirmed by the success of the improvement activity undertaken, *"the proof of the pudding is in the eating"*[9]. If the improvement theory developed from the observations made is not correct then the

[9] John Bartlett (1820–1905). Familiar Quotations, 10th ed. 1919. Taken from 'Don Quixote Part II, Chap. xxiv' by Miguel de Cervantes Saveedra (1547-1616) http://www.bartleby.com/100/733.75.html [accessed 8th February 2011]

improvement activity would likely fail as the implemented countermeasures would not be focused in the right area/right way.

This is confirmed by Brydon-Miller *et al.* (2003) who argue *"AR is much more able to produce 'valid' results than ordinary or conventional social sciences"*. The collaborative approach adopted by AR also produces a joint improvement effort between the researcher and the personnel in the business involved. This collaboration would suggest a good ethical approach to research resulting in the development of trust between the researcher and the personnel involved in the AR therefore reducing the likelihood of the observed personnel deceiving the researcher.

The collaborative relationship adopted between researcher and researched as well as 'the proof of the pudding is in the eating' confirmation of success suggest that AR projects that are successful will probably always achieve high levels of internal validity. An example of AR presented by Warren (2003) provides an illustration of this high level of internal validity. In the study the researcher spends two years 'in-situ' at the company in an interactive participative role that successfully brings about improvement that was *"built, maintained and sustained..."*.

Relating internal validity to this project the avoidance of going native is not applicable as the researcher will be a native from the start taking an overt action research approach to data collection compared to ethnographic covert approach. Data collected is validated by the organisation's employees as they work in collaboration with the researcher.

External Validity

LeCompte and Goetz (1982) suggest external validity relates to the level of generalisation possible across social settings. They argue that unlike internal validity, which is expected to be high in qualitative research, external validity presents a problem due to the tendency to employ case studies and small samples. For ethnography this is typically the case with the researcher focusing on immersing themselves in a group for a significant period of time to observe the behaviour and understand other people's realities. The focus of understanding is always specific to the group being observed and therefore it is impossible to generalise to other social groups from the findings.

However, in the example of ethnography presented by Deldridge (1995) the findings from the factory studied are generalised to cover other factories where Japanese techniques are employed. Whether this is accurate or not can only be proven by checking for the same phenomenon in all other factories which is not realistic.

Similarly to ethnography, AR is focused on one particular company rather than a sample of the population. Again the external validity is therefore restricted to the social context in question (Brydon-Miller *et al.*, 2003). In the example presented by Warren (2003) there is no attempt made to generalise about the findings even to similar companies in the same social context. The very nature of AR means that the improvements made are bespoke to the unique needs of the business in question and would not be applicable to other businesses.

However, Checkland and Holwell (1998) suggest that a *"serious organised process of AR can be made to yield defensible generalisations"*. An example is presented where a dozen action research projects investigated the contracting process in the National Health Service resulting in a generalisation of findings (Checkland, 1997).

In relation to this project the external validity of the research findings is limited in some way to the level of intervention/reduction taken in the action case design as suggested by Braa and Vidgen (1999). However, the researcher has deliberately chosen an objectivist ontology standpoint to allow for the development of the value improvement model conceptual framework external to the influences of social actors (Bryman, 2001).

Internal Reliability

LeCompte and Goetz (1982) suggest internal reliability relates to the agreement between joint researchers as to what they see and hear. If there is more than one researcher it is important to check they are interpreting their observations of the 'actors' in the same way. If there is agreement then the internal reliability is higher.

Interestingly, this definition matches closely with the approach taken for measuring the reliability of mechanical systems; when there is more than one mechanical system operating in parallel the overall system will be more reliable as it has redundancy present (Davidson and Hunsley, 1994). The internal reliability is also related to validity; if there is weak internal reliability then the validity will also be negligible. For example, if two ethnographers have differing observations for the same social setting then the resultant theories developed will be questionable as will the validity (internal and external).

For this research project the internal reliability is dependent on the agreement of the facilitated teams working to collect any data and agree on its reliability and validity. Using an overt collaborative team approach to data collection ensures high levels of internal reliability are achieved.

External Reliability

LeCompte and Goetz (1982) argue external reliability as the degree to which a study can be replicated. As with external validity this is a difficult criterion for qualitative researchers to achieve due to the subjective nature of the research where typically, it is impossible to 'freeze' a social setting.

For ethnography there are particular methods that can be employed to help. One suggestion is to take up the same role of the original ethnographer and copy the techniques for interaction adopted. Gold (1958) suggests the role adopted could be one of an 'involvement' position where they are a 'complete participant', usually covert with their true identity hidden (Roy, 1958); or at the other end of the spectrum, one of a 'detachment' position where they are a 'complete observer', being overt and a 'disinterested spectator' (Roethlisberger and Dickson, 1939).

In Deldridge's (1995) example the role adopted was one of an overt observer using analysis of documents and interviews to support the observations. This approach should be replicable. For AR the question of whether the study can be replicated is open to discussion with regard to relevance.

As already explained for external validity, the AR approach is always bespoke to the needs of the business undergoing the change and it is therefore unlikely that another researcher would be able to replicate the exact approach adopted. The fact that the business has undergone a change makes it impossible to duplicate the exact same cycle. Warren's example of AR is a good illustration of this; it would be impossible for another researcher to replicate the study in the same company. However, the methods employed could be tried in a similar business with similar opportunities.

Summary

Overall, the main objective of ethnography is to tap into the culture being observed to present a written account of the findings. The main criterion for measuring this achievement is not external reliability, the ability for the study to be repeated. Neither is it internal reliability, where the study is guaranteed by another researcher who observes the same things. Also, neither is it external validity, where the findings can be generalised to similar social contexts. The main criterion is internal validity, to have a deep understanding of the observations made to develop applicable theories.

Unfortunately it is difficult to know whether the researcher has actually achieved this deep understanding as the internal validity is dependent on interpreting the 'actor's performance' when they are being observed. There is also a possible relationship between the level of covertness/overtness and the guarantee of internal validity. The more covert the role adopted, the higher the level of assurance for the internal validity and the reverse for overtness. This brings into question the relationship between the role adopted and the ethics involved. Typically, the more covert the role the less ethical it will be.

For AR the same measurements of success criteria are applicable. However, for AR the problem of knowing whether the internal validity is high is not so difficult. The collaborative approach adopted means the researcher is a part of the observed, so to speak, looking at their role as well as the social aspects of the personnel in the company. This collaboration also means there is not the issue of ethics that exists for ethnography.

In relation to this research project the hybrid research design using an objectivist ontology, combination of case study and action research using process mapping through facilitated teams, provides good levels of internal and external validity as well as internal and external reliability.

2.4 Ethics

Collis and Hussey (2003) warn that ethical considerations are not just important in the natural sciences, but also important in social research. They suggest a number of different ethical issues to be considered: -

- **The subject firm**: what if the company you are researching are doing something illegal?
- **Confidentiality/anonymity:** again, what if the participant you are researching is doing something illegal?
- **Informed consent:** potential participants should be informed and agree to participate.
- **Dignity:** research should not ridicule or embarrass participants.
- **Publications:** must be honest and not falsified to suit the researcher.

With reference to the ethical considerations suggested by Collis and Hussey (2003) with relevance to this project the informed consent, dignity and publications are applicable. Approval from the organisation's Senior Management Team and personnel involved in the research will have been gained; any interviews to be carried out will not be impersonal and respect the respondent's dignity; and finally, any publications to be presented whether inside or outside of the organisation will be reviewed by the respondents for approval before publication.

2.5 Discussion

The research strategy for this study is not totally positivistic or will use action research as an overall research design but both positivism and action research have attributes that are included and therefore a hybrid research design including elements of both is identified. Braa and Vidgen (1999) argue for the use of a hybrid of action research and case study, the action case approach which encompasses both positivistic reductionism and interpretivist understanding, both of which cause intervention at some level when carrying out in-context research; thus suggesting the researcher can never totally be an *"objective outsider or a subjective insider"*.

The two important criteria for establishing and assessing the quality of research, reliability and validity (Bryman and Bell, 2003) have been discussed and the overall research strategy using an objectivist ontology, combination of case study and action research, should provide good levels of internal and external validity as well as internal and external reliability. Additionally, the overt and collaborative action case design working in partnership with the organisations indicates there will be no ethical concerns for the research investigation.

Although there are minor differences between the action case design and the ideal approach for this project, the action case approach is adopted as the overall research design for this study and the ontology standpoint of objectivism is taken viewing the conceptual framework presented as external to the influences of social actors. Data collection methods to be used include: observation of work practices; one-to-one interviews with employees; group discussions; documentation analysis & participation in company activities working as an engineering or operations manager.

Developing a research methods model for this thesis, the Author presents Figure 2 which builds on the action case study approach transferring prior knowledge and business needs into a cycle of: Opportunity→ Planning→ Intervention→ Observation→ Reflection→ Learning→ Writing-Up→ & Publication. This continuous knowledge accumulation process, through multiple action case study interventions, informs the overall thesis development identifying further research opportunities through concurrent in-context research.

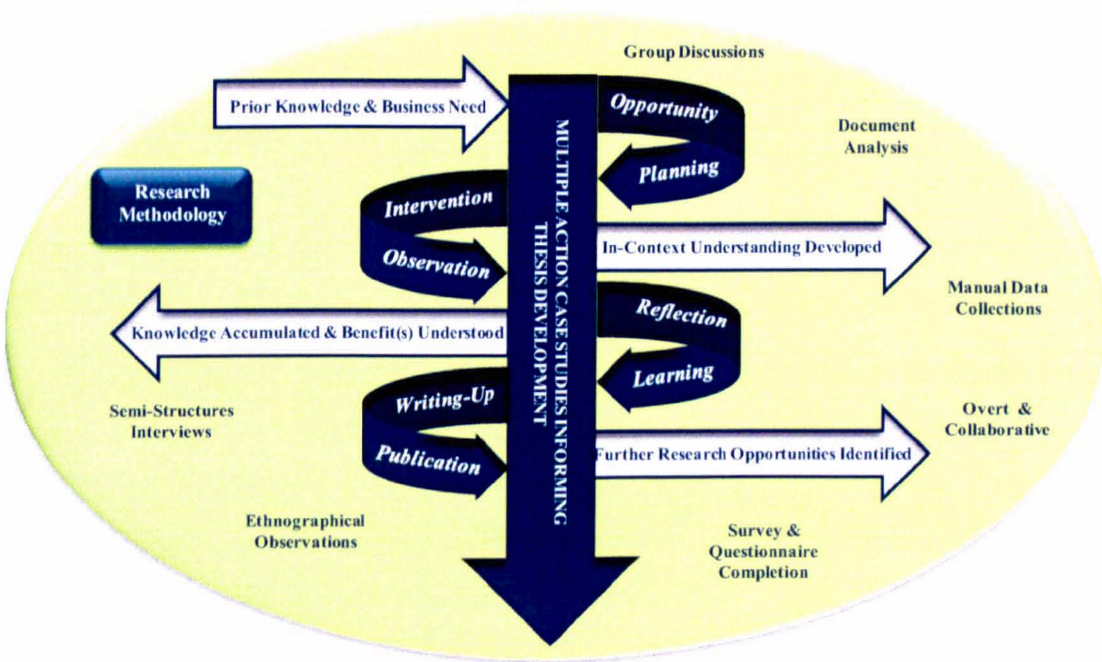

Figure 2: Research Methods Model for this Thesis

2.6 Conclusion

This section of the thesis has presented the research strategy and design to be used in this investigation. The next section will further set the context for the research investigation through a captious and taxonomic review of the lean and six-sigma literature in the development of a value improvement model for repetitive processes.

Chapter 3: Review of Six-Sigma & Lean

3.1 Introduction

This section of the thesis will take a captious and taxonomic review of the body of knowledge for both the six-sigma and lean conceptual frameworks. The six-sigma framework for process improvement will be reviewed as for its suitability as a useful and transferable framework in the development of a value improvement model. Linking the more traditional quality improvement PDCA cycle to the contemporary six-sigma DMAIC framework provides a more holistic structure for value improvement. Combining the two elements brings together the continuous knowledge accumulation from the PDCA cycle with the more linear and structured DMAIC framework. Building on the structured approach to knowledge accumulation, the lean conceptual framework will be reviewed as a useful philosophy for understanding and maximising value in repetitive processes.

3.2 Six-Sigma

3.2.1 Overview

Snee and Hoerl (2003) argue six-sigma is one of the best known approaches to process improvement with many large US companies reporting million dollar savings to their bottom-line thanks to these business improvements (Snee, 2004). According to Laux (2005), the President of the Sigma-Academy in the US, the roots of six-sigma as a measurement standard have been around for many years and can be traced back to Frederick Gauss (1777-1885) who introduced the concept of the normal distribution curve. Early in the Twentieth Century, Shewhart (1931), in his work on statistical process control, showed that three sigma from the mean is the point where a process requires correction.

Six-sigma as it is known today has its roots firmly planted in the workings of Dr. Mikel Harry who was a senior staff engineer at the Motorola Electronics Group during the late 1970s and Bill Smith a Vice President and Quality Assurance Manager (Brady and Allen, 2006). Six-sigma is also now synonymous with General Electric thanks to the claimed billion dollar success (GE, 1999) under the leadership of its Chairman, Jack Welch (Welch and Byrne, 2001).

The statistical objective of six-sigma is to reduce the variation in every process to such an extent that a spread of 12σ (6σ either side of the mean) fits within the specification limits. To put this in perspective (Baker, 2003) presents an example of six-sigma using a golf analogy to understand the significance of this near perfect, zero defect (Crosby, 1980), process capability: -

"If you play 100 rounds of golf per year, with 18 putts per round then:
- *2σ quality equates to 6 missed putts per round*
- *3σ quality equates to 1 missed putt per round*
- *4σ quality equates to 1 missed putt in 9 rounds*
- *5σ quality equates to 1 missed putt in 2.33 years*
- *6σ quality equates to 1 missed putt in 163 years"*

According to McAdam & Evans (2004), six-sigma is considered primarily a problem solving methodology using a sequential system known as DMAIC: Define, Measure, Analyse, Improve, and Control. The DMAIC system can be used to improve a single process (Deshpande *et al.*, 2004) and Steel (2004) also suggests it can be used as a 'slow burn' pilot for six-sigma projects before the 'big bang' companywide implementation is made.

The DMAIC process has similarities with the PDCA: Plan, Do, Check & Act cycle originally developed by Shewhart (1939) in the 1930s and later taken to Japan and made famous by Deming (1986) after World War II. Figure 3 shows the six-sigma DMAIC sequential process and the Shewhart/Deming PDCA cycle as they are commonly used today (and as used by the Author in a practitioner environment).

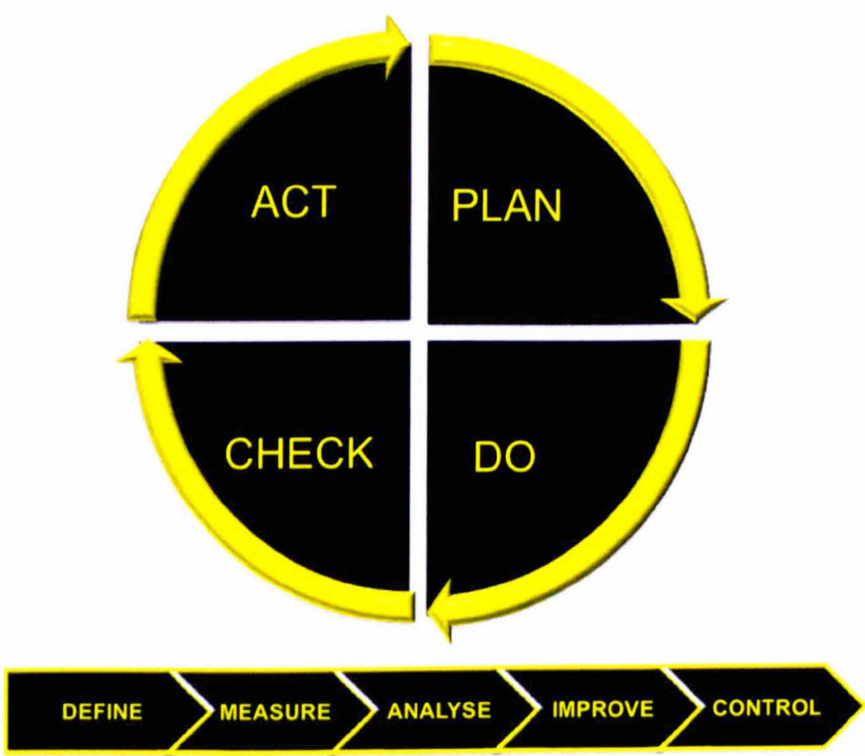

Figure 3: PDCA & DMAIC

3.2.2 DMAIC

The DMAIC cycle is worthy of further investigation as to its suitability for this investigation potentially as a framework for the value improvement model for repetitive processes, as Goh (2010) argues in a recent review of six-sigma in industry, "*..six-sigma is now recognised for providing a framework for improving quality*" and subsequently"*...the whole can be greater than the sum of the components when this approach is applied*". This next section will therefore review each of the five stages in the DMAIC framework gaining an understanding of the usefulness in the development of a value improvement model for repetitive processes.

Define-MAIC

The DMAIC cycle has been introduced as a methodology for solving problems in a structured manner using the facts available. Juran & Gryna (1988) define a project as *"a problem scheduled for solution"* and the first stage in the DMAIC process, Define, simply is a case of putting this problem scheduled for a solution, down on paper.

Keller (2001) suggests this should be done by developing the project scope, its objectives, metrics and deliverables incorporating all of these into a project charter that serves as a contract between the project team and the project sponsor. Pande & Holpp (2002) also argue that a project charter should be developed as a project blue print that defines and narrows the project's focus, clarifies the results being sought, confirms the value to the business, establishes boundaries and resources for the team, and finally helps the team communicate its goals and plans.

A fundamental of six-sigma is the relationship between the output of a process known as the Y, and the inputs known as the Xs. According to De Feo & Barnard (2004), what comes out of a process is determined by what goes in, the output Y is a function of the input Xs. In maths terms this is stated as $Y = f(x1, x2, xn)$.

The DMAIC cycle must identify the Xs that are negatively influencing the Ys then either by eliminating or changing the Xs, put in controls so the original Xs & Ys cannot return. A method of identifying both the scope of a project and an overview of the inputs and outputs is known as a SIPOC diagram (a simple high level process map). George *et al.* (2004) define the SIPOC acronym as suppliers, input, process, output and customers detailing each element as follows:

- **Suppliers**: the individuals or groups who provide whatever is worked on in the process (e.g. information, forms, material).
- **Input**: the information or material provided.
- **Process**: the steps used to do the work.
- **Output**: the product, service, or information being sent to the customer.
- **Customers**: the next step in the process, or the (external) customers.

D-Measure-AIC

Measure is the logical follow up to Define and also acts as a bridge to the next stage, Analyse. Pande & Holpp (2002) suggest there are two main objectives in the measure stage: -

1. To gather data to validate and quantify the problem/opportunity.
2. To begin teasing out facts and numbers that offer clues about the causes of the problem.

George *et al.* (2004) suggest that the Measure stage is the key to six-sigma's success. The collection of data combined with knowledge and experience will help prevent the improvement being just a bit of tinkering with the process ending up with a short lived improvement that may, in the end, do more damage than good.

De Feo & Barnard (2004) argue the main purpose of the Measure stage is to identify and document the process parameters (or the input variables Xs) that affect process performance and product characteristics (the output variables Y) of the requirements of the customer. Keller's (2001) argument encompasses all of the theories already discussed. He argues that the measure stage is simply an evaluation of the current state of the organization or process using the metrics defined within the define stage of the DMAIC cycle.

DM-Analyse-IC

The Analyse stage involves the dissemination of the data captured in the Measure phase into useful information developing a theory of how the gap can be filled to lay the foundations and implement the improvements within the next stage of the DMAIC process.

Pande *et al.* (2000) compare the Analyse stage to that of a detective trying to solve a crime-case, laying down a warning that the usual suspects (the causes that are thought to be the root of the problem) often turn out to be not guilty or just accomplices to the real culprit. The basis of the Analyse stage is not to assume anything as these assumptions can cause the wrong thing to be corrected resulting in there not being the improvement that was anticipated.

George *et al.* (2004) suggest that another reason why improvement initiatives fail is because the analysis has been too general resulting in general changes that are targeted at general problems. George goes on to suggest a quality improvement tool that can be used to help focus the analysis and defines it as Pareto Analysis.

Juran (1995) explains the history of the Pareto principle as coming from a nineteenth century economist, Vilfredo Pareto, who studied the distribution of his country's wealth and found that most of the wealth was concentrated in a few hands and the majority of the people were in poverty. Juran (1954) re-introduced Pareto's principle and subsequently developed it into a useful management tool that can be defined as 80% of the costs of poor performance are created by just 20% of the problems; the vital few and useful many, now popularly referred to as the 80/20 rule.

Taking it one step further, Arthur (2001) suggests the Pareto principle can be applied to itself resulting in 4% of the effort (20% of 20% of the vital few) yielding 64% of the results (80% of the 80% useful many). This approach creates a focus within a focus that Arthur (2001) suggests, lets you get on with fixing what is broken rather than trying to be perfect and fix everything.

There are many other analytical tools within the six-sigma toolkit that can be used to identify the opportunities for improvement. These tools such as ANOVA, regression analysis, cause and effect diagrams and hypothesis testing are very useful in the second and third cycles of the DMAIC methodology. According to Steele (2004), during the first wave in the DMAIC process it is useful to apply simple tools and effectively look to gather the low hanging fruit around the processes before looking for more complicated solutions. This immediate and simple improvement can then be used to show how effective the DMAIC methodology is for when the second wave begins.

DMA-Improve-C

The Improve stage in the DMAIC cycle is the most important part as it is at this stage that the changes to normal practices will be decided and implemented. The –Define→Measure→Analyse- stages have only set out the problem, established a measurement of it and identified where the possible failures are. Typical tools in the Improve step include 5S (Hirano, 1995), Kaizen (Imai, 1986), TPM and OEE (Nakajima, 1988) which will all be discussed in more detail in the following Chapters.

DMAI-Control

Once the improvements have been made it is important that they are maintained at the same level. George (2002) suggests that Control can be gained by the implementation of formal documentation, training and procedures/diagrams posted at work stations.

Another Control feature suggested is the use of Statistical Process Control (SPC) to monitor the inputs to the process. George warns that a common mistake made is to use SPC on the outputs of a process thus controlling what has already happened rather than what is about to happen. Pande *et al.* (2000) suggest some guidelines that are useful for controlling the improvements made: -

1. keep the documentation simple,
2. keep the documentation clear and inviting,
3. include options and instructions for emergencies,
4. keep the documentation brief,
5. keep the documentation handy,
6. have a process for updates and revisions.

3.2.3 Six-Sigma Critique

Although six-sigma has had a lot of publicity regarding its success there are other cases where it has not been so successful and Coronado & Antony (2002) present a warning, according to David Fitzpatrick, worldwide leader of Deloitte Consultancy's Lean Enterprise Practice *"...Fewer than 10% of the companies are doing six-sigma to the point where it is going to significantly affect the balance sheet and the share price in any meaningful period of time"*.

Why is Six-Sigma not successful in all cases? Researchers and practitioners see the understanding of critical success factors (Basu, 2004; McAdam and Evans, 2004; Coronado and Antony, 2002) as key to the overall success of six-sigma projects. DeFeo & Barnard (2004) offer an insight into the reason why initiatives fail arguing that there is often a lack of long-term sustainability. They suggest the failures occur at micro and macro event levels and define micro as those activities on the shop floor or in the process and macro as those activities at senior management level such as a change in leadership.

George (2002) confirms this macro level failure and gives an example of a typical senior management failure as a lack of endorsement and involvement in the project. Eckes (2000) also explains that the managers must be involved in the creation and management of the process management system, and also participate in the projects themselves for it to succeed. Basu (2004) summarizes 4 critical success factors for the use of tools and techniques in a company-wide, six-sigma change programme:

1. Senior management commitment
2. Availability of resources
3. Well-designed education and training programmes
4. Rigorous project management approach.

Goh (2010), in a recent review of the impact of six-sigma in its twenty-five years in industry, identifies some of the key failings of six sigma. One particular failing relevant to this study is the focus on only achieving bottom line improvements to a particular process, ignoring the potential consequences to similar processes. Elaborating further, Goh (2010) suggests this failing is a result of the approach adopted by six sigma practitioners where *"there is a tendency to be obsessed with savings, stretching scenarios till they make a project look impressive..*and *...financial results seem to be everything in project conclusions.."*. Although in contrast, Montgomery (2001) argues this focus on bottom-line savings is needed to keep the management team interested.

This critique is a key factor in the context of the development of a value improvement model. As Brady & Allen (2006) argue, six sigma researchers should now focus on the development of more realistic payback models. Therefore the value improvement model being developed must aim to overcome this narrow focus on financial gains of a particular project and also provide a methodology to keep the management team interested in the improvement initiative.

3.2.4 Lean Six-Sigma

The same as six-sigma does not offer a direct approach to improving the value adding elements of a process; lean does not offer a direct approach to making the process statistically capable. George *et al.* (2004) argue that it is important to combine the different aspects of lean and six-sigma and describes the combination as:

"a methodology that maximises shareholder value by achieving the fastest rate of improvement in customer satisfaction, cost, quality, process speed, and invested capital. The fusion of lean and six-sigma is required because:

- *Lean cannot bring a process under statistical control;*
- *Six-sigma alone cannot dramatically improve process speed or reduce invested capital"*

Hoerl (2004) suggests that the effective combination of lean and six-sigma is more complicated and will in the future appear as a much larger 'overall organisational improvement system'. Hoerl also suggests that six-sigma is more suitable for 'solution unknown' problems while lean is more suitable when the solution is known ahead of time.

3.3 Lean

3.3.1 Lean and the Link to the Automotive Industry

Since its inception, when cars were hand built to order by craftsmen, the automobile industry has gone though major changes which have influenced the practices within the many heterogeneous fields of manufacturing (Lewchuk, 1987; Hounshell, 1984). The first vehicles produced utilised the new concept of a lightweight four stroke engine developed by Eugen Langen and Nicholaus Otto placing the new engine into modified bicycle frames (Waymark, 1983). It was not until 1886 when a German engineer, Karl Benz, patented the first purpose built *"motor carriage"*; the first vehicle produced on a *"commercial basis"* (Waymark, 1983).

The methods of manufacture of these early vehicles relied on the skills of *"artisans"* and *"tinkers"* concentrated in an area around France and Germany

(Altshuler *et al.*, 1984). Following on from this initial craft period Womack *et al.* (1990) suggest there have been two fundamental ideas which have further influenced the way manufacturing is accomplished.

First is the concept of "*mass production*" based on the ideas of Henry Ford (Ford, 1922) and General Motors' Alfred Sloan (Sloan, 1963). Ford (1926) was asked to define mass production for the Encyclopaedia Britannica giving the phrase its place in English vocabulary (Hounshell, 1984):

> "*.....Mass production is the focusing upon a manufacturing project of the principles of power, accuracy, economy, system, continuity and speed.*"

Altshuler *et al.* (1984) classify Ford's methodology as "*Fordism*" suggesting the approach is based on the combination of a continuous production system known as an assembly line married to a scientific management (Taylor, 1911) approach to the division of manufacturing skills and the "*routinization*" of complex work (Abernathy, 1978). Altshuler *et al.* (1984) classify Sloan's methodology as "*Sloanism*" suggesting the approach is an adaptation of Fordism using decentralised organizational techniques to manage the giant enterprises the automakers had become (Sloan, 1963).

The second concept presented by Womack *et al.* (1990), "*lean production*", was pioneered by Eiji Toyoda (Cusumano, 1985) and Taichii Ohno (Monden, 1983; Ohno, 1988) in conjunction with Shigeo Shingo (Shingo, 1981; 1989) at the Toyota Motor Company, Japan in the 1950s (Holweg, 2006). According to Imai (1986), Toyota evolved its production strategy out of the need to develop a system for manufacturing small numbers of many different automobiles with limited resources contrasting the western approach that was based around producing large numbers of similar vehicles.

Toyota originally labelled this strategy "*innovation in production management*" (Cusumano, 1988) with the term "*lean*" first appearing in the published work of John Krafcik (1988) who set out to understand Toyota's production system as part of the International Motor Vehicle Project (IMVP, 2005) at the Massachusetts Institute of Technology (MIT) in the USA.

Krafcik (1988) introduced the term lean to distinguish the Toyota Production System (TPS) (Shingo, 1981; Monden, 1983; Ohno, 1988) from a "*buffered*" paradigm, suggesting that Ford's original mass production concept was in fact lean, but not flexible, contrasted to Fordism (Altshuler *et al.*, 1984) today, which is buffered and rigid; antithetical to the principles of TPS. Figure 4 is a reproduction of Krafcik's (1988) categorisation model of production systems showing the distinction between TPS and Fordism.

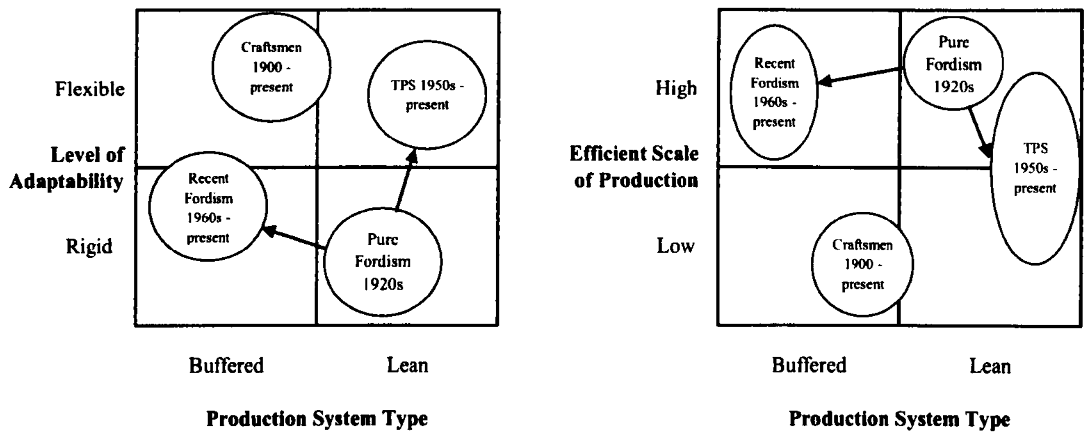

Figure 4: A Categorisation of Production Systems (Krafcik,1988)

Pine (1993) argues mass production has become outmoded and is no longer an effective means of production. Liker (2004) agrees suggesting mass production is now anachronistic to the requirements of customers who demand flexibility and choice in their consumer requirements whereas the axiomatic approach of lean production, now seen as the paradigm for operations (Katayama and Bennett, 1996), addresses these requirements directly by delivering:

> *".....the need for fast, flexible processes that give customers what they want, when they want it, at the highest quality and affordable cost".*

Forza (1996) argues that lean undoubtedly surpasses Fordism suggesting that it is better from a production point of view offering gains in flexibility and quality and from a human point of view offering worker involvement rather than bureaucratic controls.

Holweg (2005), building on previous research (Holweg and Pil, 2001), suggests complimentary to flexibility is the need to be responsive which a lean approach can also deliver through its persistence on lead-time reduction and customer focus. However, although Holweg (2005) argues lean can be flexible and responsive it can also be perceived as being inflexible through the focus on levelling demand, especially in more volatile markets (Katayama and Bennett, 1996; Harrison, 1999). Spear & Bowen (1999) suggest this "*apparent paradox*" comes from a failure by imitators (lean) to fully understand the Toyota Production System, focusing on the tools and practices they have seen when visiting Toyota facilities and confusing them with the overall system itself.

The proven success of lean production techniques within many industries (Katayama and Bennett, 1996; Womack and Jones, 1996a; 1996b; Naim, 1997) as well as the suggestion that there are inherent weaknesses (Williams *et al.*, 1992; Pilkington, 1998; Harrison, 1999) warrants further enquiry of the theoretical frameworks informing the lean concept.

3.3.2 Evolution of Lean

Hines *et al.* (2004) argue there have been four main stages in the evolution of the lean concept. The "*pre-concept*" awareness stage -1980 to 1989- presented diffuse empirical based material relating to the methods used within Japanese manufacturing industries, primarily in the automotive industry and in particular Toyota (Hayes, 1981; Krafcik, 1988; Mather, 1988; Monden, 1983; Ohno, 1988; Schonberger, 1982; 1986; Shingo, 1981; 1989).

The ensuing seminal work of Womack *et al.* (1990)[10] introduced the "*lean production*" concept, as it is know today, suggesting a focus on waste elimination (muda[11]) of individual processes; at what could be considered the micro level of the overall operation. The conceptual development was based on the findings from a five-year research project (IMVP, 2005) based at MIT in America.

Taking a bold and heretical approach creating mechanisms for industry, government &university interactions at an international level, the project team set six criteria for which its success would depend on:

1. Thoroughness
2. Expertise
3. A global outlook
4. Independence

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[10] Although Krafcik (1988) first labelled the Toyota Production System as lean, Womack *et al.* (1990) are widely recognised as producing the seminal work outlining the principles of lean production.

[11] Muda is the Japanese term for waste that encompasses all the non-value adding elements of a process.

5. Industry access
6. Continuous feedback.

To achieve the criteria, specialists from the automotive industry -now working in academia- were sourced from around the world to carry out case study investigations within the global automotive industry.

In summary of the project, Womack *et al.* (1990) suggest the lean production concept combines the best elements of craft production with those of mass production, offering a pluralist approach which focuses on delivering:

"....reductions in costs per unit and dramatically improving quality while at the same time providing an ever wider range of products and ever more challenging work".

Quantifying the potential of the lean production concept, Womack *et al.* (1990) argue when compared to mass production, the lean factory requires:

- ½ the human effort in the factory
- ½ the manufacturing space
- ½ the investment tools
- ½ the engineering hours
- ½ the time to develop new products

Overall, the study revealed the existence of a 2:1 productivity difference between car assembly plants in Japan and those in the West. These findings lead to extensive industry "*soul-searching*" (Lewis, 2000) which resulted in further benchmarking studies confirming the lean production project revelations (Andersen-Consulting, 1993; 1994; Boston-Consulting-Group, 1993; IBM-Consulting-Group, 1993).

In 1994 the tangential concept of a "*lean enterprise*" (Womack and Jones, 1994) was introduced as a development of lean production taking a broader perspective of the extant relationships between disparate processes within the overall system of manufacture; at what could be considered a more macro level of the overall operation. The ideas behind the lean enterprise were further complemented by a set of principles presented as "*lean thinking*" (Womack and Jones, 1996a; 1996b) summarised as the 5 steps to becoming lean:

1. Specify value
2. Identify the value stream

3. Make the value creating steps flow
4. Promote a *"pull"* culture
5. Pursue perfection

Supporting the waste elimination and value adding focus of the lean principles, Womack & Jones (1996a) introduce the concept of customer value and define three categories which must be understood to improve a process:

1. Value adding (VA): what the customer expects to pay for
2. Non-value adding (NVA): pure waste, what the customer does not expect to pay for.
3. Necessary but non-value adding (NNVA): inherent waste from existing practices that must happen to complete the process, what the customer does not expect to pay for.

Concurrent with the fundamental conceptual work of Womack *et al.* (1990) was the dissemination of the lean concept to other areas of operations management research. This research culminated in the *"lean supply"* (Lamming, 1993; 1996) and *"lean logistics"* (Jones *et al.*, 1997) concepts. Other simultaneous and tangential work led to the development of new tools to enhance the original concepts: Seven Value Stream Mapping Tools, (Hines and Rich, 1997; Hines *et al.*, 2000); Value Stream Mapping (Rother and Shook, 1998) & Big Picture Mapping (Jones and Womack, 2003). All with the same objective of eliminating the seven non-value elements in processes as originally specified by Ohno (1988):

1. Overproduction
2. Waiting
3. Transport
4. Inappropriate processing
5. Unnecessary inventory
6. Unnecessary motion
7. Defects

At the operational level the removal of waste is a key element of lean production and Schonberger (1982) introduces three categories of waste typically found in manufacturing plants:

1. Muri, meaning excess, producing more than is required.

2. Muda, meaning waste, in all of its forms
3. Mura, unevenness, materials parts and goods should all flow at an even rate and not fluctuate.

The most recent phase in the evolution of lean has seen the introduction of the "*lean consumption*" concept (Womack and Jones, 2005a; 2005b) which is described as "*...a necessary and inevitable complement*" to lean production and is about "*... providing the full value that consumers desire from their goods and service, with the greatest efficiency and least pain*".

Similarly to other dimensions of the lean concept (Lamming, 1993; 1996; Jones *et al.*, 1997) the principles correspond closely with the 5 steps to becoming lean (Womack and Jones, 1996a; 1996b). This more holistic approach encompasses new ideas and in particular is interested in supplying what the end customer wants, where they want it, when they want it and without wasting their time at any time; an end customer satisfaction focused approach to the lean concept.

3.3.3 Critique of Lean

Despite the great success of the lean concept there have been concerns raised regarding the research that informed it and questions asked about its actual competitive impact (Lewis, 2000).

Williams *et al.* (1992; 1994) heavily criticise the validity of the conceptual work of Womack *et al.* (1990) citing it as "*...a manifest absurdity of evangelical Japanolatory...*" borrowing old productivity measures used in an "*...increasingly loose and rhetorical way*". Williams *et al.* (1994) argue the research methods employed were ineffective, using constructs of the past based on secondary data, and constructs of the present which ignore available data such as company reports, accounts and official statistics.

This concurs with Katayama & Bennett (1996) who also question the validity of the work suggesting it does not take in to account the effects of Japan's "*bubble economy*" of the late 1980s in market conditions where owners were encouraged to scrap their cars and replace them with new ones. Lewis (2000) agrees, suggesting the lean production model may have "*...reflected particular market conditions at a specific point in time*". Setting out to quantify these critiques, Ward (1996) and

Pilkington (1998) provide data showing how some countries were actually performing much closer than Womack *et al.* (1990) had suggested (*cf.* Table 5) [12].

	1986		1987		1988		1989		1990	
Japan	**67,075**		**84,538**		**103,433**		**105,433**		**107,874**	
U.S.A.	77,787	1.16	80,403	0.95	89,034	0.86	94,912	0.90	89,219	0.83
U.K.	32,263	0.48	39,984	0.47	46,720	0.45	50,547	0.48	53,340	0.49
Canada	57,350	0.86	58,649	0.69	71,943	0.70	76,311	0.72	74,105	0.69
S. Korea	18,757	0.28	23,607	0.28	28,069	0.27	34,063	0.32	44,539	0.41
Spain	24,571	0.37	42,146	0.50	49,443	0.48	48,341	0.46	53,891	0.50
Sweden	42,776	0.64	52,413	0.62	63,433	0.61	62,723	0.59	63,229	0.59

Table 5: Comparison of $ Value-Add per Auto Industry Employee, 1986-1990
(adapted from Ward, 1996 & Pilkington, 1998)

Taking the average productivity ratio over the 5 year period using the data from Pilkington (1998) and Ward (1996) the USA actually achieved a level of 0.94; nearly the same as Japan thus nullifying the claim of Womack *et al.* (1990) that there existed a 2:1 productivity difference between the US and Japan (*cf.* Figure 5, developed by the Author).

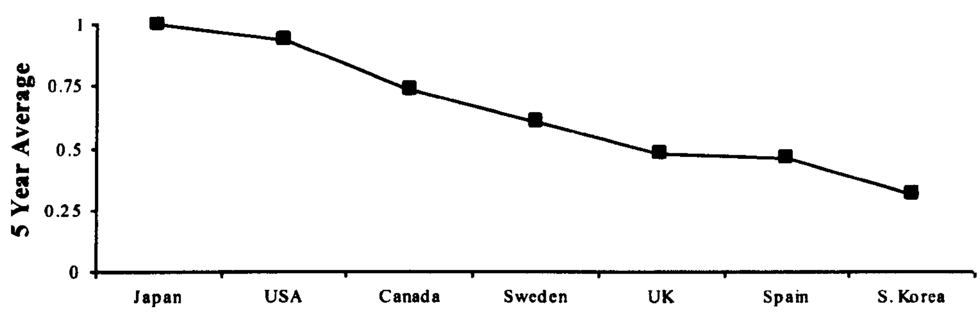

Figure 5: Average Productivity Ratio per Country 1986-1990

Although worthy of notation in its own right, the criticism of the research methods employed by Womack *et al.* (1990) are also important as they impact the validity of the research informing the concept of lean. Affecting the usefulness of the lean concept, this has lead to further criticism which Hines *et al.* (2004) classify in the following categories: lack of contingency; lack of consideration for human factors and a narrow focus at the shop floor level.

Reviewing the lack of contingency critique of lean, Hines *et al.* (2004) present an example of a paradoxical situation where piecemeal applications of lean

[12] Each column shows the $ value adding contribution per year along with the level of productivity per employee in that year. For example, in 1986 the USA achieved an average $77 787 per employee with a productivity per employee of 1.16.

have resulted in the most productive car plants in Europe producing the highest levels of finished stock. Overcoming this problem the proposal is made for cars to be built-to-order as suggested by Holweg and Pil (2001) and originally proposed by Monden (1983). Other critiques suggest that truly lean systems lack flexibility in terms of *"space to experiment"* and *"time to think"* (Lamming, 1996).

Taking a system reliability perspective, Smart *et al.* (2003) argue high levels of leanness can remove levels of system redundancy or organizational slack that are necessary to deal with contextual uncertainty and non-routine behaviour which in the case of the automotive industry would be consumer requirements. This argument is backed by Lawson (2001) who proposes slack is required to support system interdependencies and when this is ignored entire systems become vulnerable.

Presenting an example, Lawson (2001) reviewed the problem encountered by GM in 1998 when its workforce went on strike shutting down all of the North-American operations. Without the parts from the striking plant, 29 assembly plants had no material to build cars. This resulted in the lost production of 576,000 vehicles estimated at $2.2 billion in lost sales (Blumenstein, 1998).

Reviewing the human factor critique and narrow focus at the shop floor level together, Hines *et al.* (2004) suggest viewed through a Marxist lens, lean production can be seen as de-humanising and exploitative to shop floor workers (Williams *et al.*, 1992). Green (1999) concurs arguing assumptions made in Womack and Jones (1996b) are uncomfortably similar to those of Taylor (1911) suggesting lean uses increased management control legitimized as management through customer responsiveness; "*Muda is eliminated, Karoshi*[13] *is the price to be paid.*"

According to Maccoby (1997) this new form of Taylorism is no different to the monotonous and iterative tasks repeated every 60-90 seconds in traditional mass production. Tangential to these concerns is the involvement of shop floor workers in improvement activities. Rinehart *et al.* (1997), during their study of a GM-Suzuki joint venture, found workers were encouraged to participate in developing improvements thus expecting them to design the very system that oppresses them.

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[13] *Karoshi* is a Japanese word used to describe the sudden death or severe stress resulting from being overworked.

Other studies, this time at the Nissan plant in the UK, deemed as the most productive plant in Europe (Hines *et al.*, 2004), argue Nissan's supposed regime of flexibility, quality and teamwork translates in practice to one of control, exploitation and surveillance (Turnbell, 1988; Garrahan and Stewart, 1992).

One final critique of lean is presented by Cusumano (1994) who argues there are also consequences to the adoption of a lean approach. For example, traffic levels increase and in Japan this has led to roads becoming grid-locked as factories and retail stores want just-in-time deliveries. Perhaps the argument presented by Cusamano (1994) is even more applicable in the UK where main roads are currently gridlocked during the rush hour and small incidents create long tail backs for commuters and commercial vehicles. Therefore, perhaps the fundamentals of lean applied to a factory setting are easily managed and controlled, but when the lean principles are applied to areas where influences are out of the control, the approach is not so easily applied.

Understanding the impact of lean from a sustainability perspective is therefore an important factor and some practitioners have turned this around and are claiming the successes of a 'green lean' approach although from an academic perspective, Mollenkopf *et al.* (2010) suggest there are gaps in the body of knowledge. Even the Author has attempted to apply lean thinking principles in the development of a sustainable airport value improvement model briefly presented in Chapter 11 of this thesis (Gibbons and Attwood, 2011). However, the delivery of a sustainability lean model is not something that has been researched thoroughly and therefore provides an area for future research at a holistic level understanding the consequences of change at a more strategic level than is normally applied in lean initiatives.

Acknowledging the criticisms of lean, Hines *et al.* (2004) propose a framework to help better understand the application of lean and its relationship with other operational level tools (*cf.* Figure 6). The early conceptual work of Womack *et al.* (1990)'s lean production paradigm is presented as a sub-system of lean thinking (Womack and Jones, 1996b) supplemented by other concepts considering production capacity, quality, responsiveness of the manufacturing system, demand variability, availability of production resources and production control resources; all with the objective to eliminate waste.

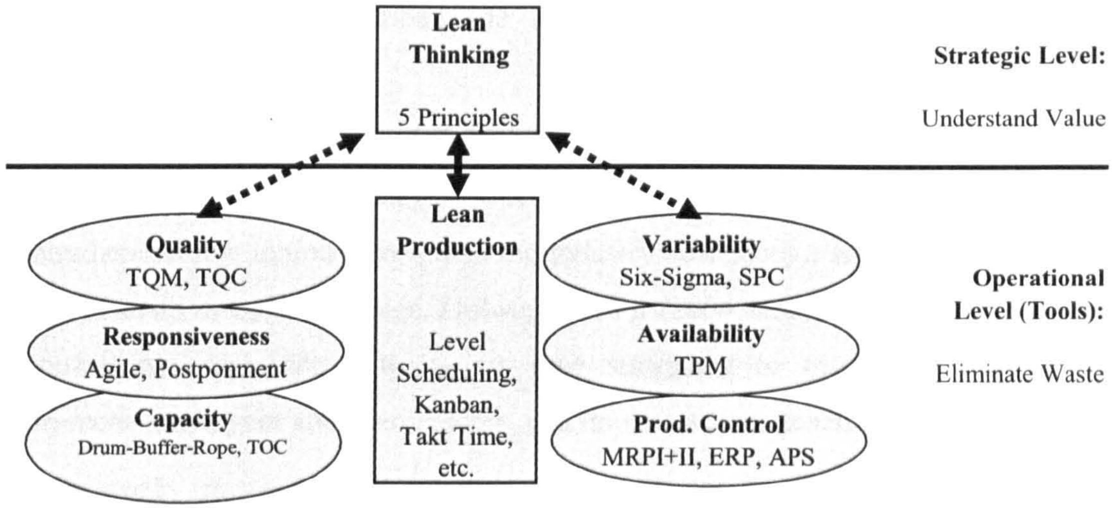

Figure 6: Lean - A Framework (Hines *et al.*, 2004)

At a strategic level, lean thinking (Womack and Jones, 1996b) sits alone and is relevant to all aspects of the framework with the goal of understanding value creation and customer value. Therefore the focus at the strategic level of lean thinking is effectiveness and the focus at the operational level of lean production is efficiency.

Looking at the model from a critical perspective it could be summarized as using heterogeneous concepts homogenized into an egocentric typology with the objective of overcoming previous critiques. Also, missing from the framework are details of its operability and how these disparate concepts interface. More importantly, there is no mention of, or any reference to, understanding the de-humanising effects and flexibility the concept has been so heavily criticised for. This leaves the framework open for further critique and suggests there is still room to improve the lean concept to where it set out to be in the first place, a transferable version of the Toyota Production System (Womack *et al.*, 1990).

3.3.4 Problems with Lean in the Automotive Industry & Future Plans

According to Maxton & Wormald (2004) the scale of the automotive industry is so grand, and its influence so vast, it is difficult to visualise its true extent. By attempting to put it into perspective Maxton & Wormald (2004) describe it as the world's largest single manufacturing activity, producing over 1 million new cars and trucks per week; using 40% of the world's rubber and 25% of the world's glass. With each vehicle comprising of some 8,000 individual parts, some 460 billion individual components must be produced around the world every year it is no wonder then that

Drucker (1946) once described the automotive industry as *"the industry of industries"*.

Today the industry is finding it hard to adjust to extant challenges and as Maxton & Wormald (2004) suggest, there are now many problems caused by internal contradictions that inhibit reform and the industry now faces a stark choice between years of strife or radical change. Holweg and Pil (2004) concur, suggesting vehicle manufacturers and their partners are now struggling to meet the demands of customers, employees and shareholders, and the industry in general is suffering from:

> *"...layoffs, abysmal profit margins, long waits for popular models, skittish shareholders, dubious investors, souring development and marketing costs - it suffers just about every plague in Pandora's Industrial box."*

Findings from an industry survey published in the Economist (2004) quantify some of the problems identified by Holweg & Pil (2004) suggesting on average profits have dropped from around 20% in the 1920s to around 10% in the 1960s and now stand at less than 5% with some volume vehicle manufacturers actually making a loss. Supplementing this business community viewpoint is a plethora of news reports highlighting some of the more specific problems affecting vehicle manufacturers.

For example, Doran (2005) reports that General Motors (GM) have been forced to negotiate with unions to implement headcount reductions of 25,000 as well as a series of factory closures and planned reductions of £8.5 billion from workers' healthcare plans. GM are not alone, Ellison (2005) details some of Ford's problems citing that the company has reported a net loss of £162 million in the third quarter of 2005. Subsequently Ford are expected to close more factories and cut thousands of jobs and to report a $1 billion-plus loss from their North American automotive arm (Times, 2005). In the UK the problems have led to the bankruptcy and closure of vehicle OEMs[14] such as MG Rover.

Other vehicle manufacturers, such as Peugeot (Buckley, 2006), are now closing their factories in the UK and moving production to areas with cheaper labour costs. The problems at vehicle manufacturers has resulted in a *"domino effect"*

[14] OEM is commonly used as an abbreviation for Original Equipment Manufacturer.

(Economist, 2005) across the industry with bankruptcies occurring at some of the vehicle manufacturers main suppliers including, Tower Automotive, Venture Industries and Oxford Automotive and the widely publicised Delhi (Simon, 2005).

Looking to overcome some of these problems in 1999 a three-year research project was established to investigate the feasibility of building cars to customer order within three days (3DayCar, 2001). The *"3DayCar"* (3DC) project brought together expert researchers from three UK institutions – the International Car Distribution Programme (ICDP, 2005) based in Solihull; the Innovative Manufacturing Research Centre (IMRC, 2005) based at Bath University School of Management; and the Lean Enterprise Research Centre (LERC, 2005) based at Cardiff University. Sponsorship of the £1.5 million project came jointly from the Engineering and Physical Sciences Research Council (EPSRC, 2005) and 20 industrial sponsors from all areas of the new car supply chain. The overall aim of the 3DC project was (ICDP, 2001):

> *"...to establish how the automotive supply chain could move from a predominantly 'stock push' system to one that built most cars to customer order and delivered them within short lead times – promising significant benefits to manufacturers, suppliers and customers."*

The 3DC project title was adapted from the 'Nine Challenges' reported in Hall and Tonkin (1989) who suggest the industry should abandon the mass production paradigm and focus on manufacturing only the products wanted in the quantities wanted: to *"...deliver a car with custom features very quickly – within three days after ordering"*. Although not seen as a specific target, where every car is to be delivered to the customer within 3 days, the overall objective of the actual project (as opposed to Hall and Tonkin's (1989) target) is more about *"...the capability of supplying a built to order car to the most demanding customers, within an acceptable and achievable timeframe"* (ICDP, 2001).

The 3 day car title was deliberately chosen as a provocative antithesis inciting radical change which subsequently forced fundamental questioning of the many steps within the extant car manufacture supply chain (ICDP, 2001). A change in strategy was seen as essential to move from the current push system – where cars are built to forecast and stored at the most expensive part of the supply chain (Fisher, 1997), using dealers as an inventory buffer (Deldridge and Oliver, 1991; Harrison, 1996) -

to one where cars are pulled through the system - utilising "build-to-order" (BTO) strategies (Monden, 1983; Hall and Tonkin, 1989; Hall, 1993; Holweg and Pil, 2001; 2004) in order to avoid inventory costs (Holweg, 2003).

Vehicle Manufacturer	Programme Name	Order-to Delivery Target
BMW	COSP- Customer Oriented Sales Processing	10 days
DaimlerChrysler	FastCar / Global Ordering	15 days
Ford	Order-to-Delivery	15 days
General Motors	Order-to-Delivery	20 days
Renault	Project Nouvelle Distribution (PND)	Initially 14 days, revised to 21 days in 2002
Nissan	SCOPE (Europe), ANSWER (Japan, ICON (USA)	14 days
Toyota	N/A	14 days
Volkswagen	Kunde-Kunde ("Customer-to-Customer")	14 days

Table 6: BTO Programmes at Vehicle Manufacturers (3DayCar, 2011)

Quantifying the scale of the problem in the UK, Holweg and Miemczyk (2002) suggest there are some 370,000 new vehicles stored in old airfields and dealer forecourts at any one time and in Europe savings of $9 billion could be achieved by eliminating the new-vehicle stocks (ICDP, 2000). In the US, Nissan Motors estimate a BTO strategy could save $3,600 per vehicle (Agrawal *et al.*, 2001; Economist, 2001). It is no wonder findings from the 3DC project (*cf.* Table 6) suggest most vehicle manufacturers (VMs) are now investigating their own BTO projects to reduce sourcing from stock (Miemczyk and Holweg, 2004).

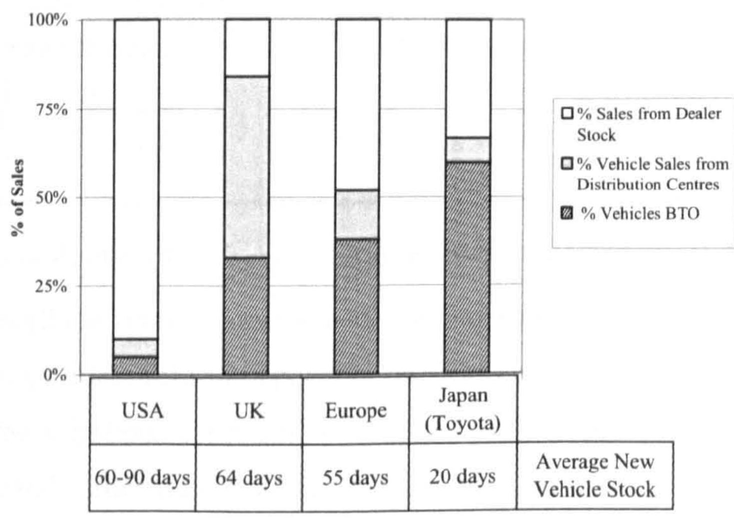

Figure 7: Sales Sourcing & Vehicle Stock (ICDP, 2001)

The current average process lead time required to build a car to order was found to be 40 days (ICDP, 2001) with typical stock levels for volume manufacturers currently at 55 days in Europe (*cf.* Figure 7) (Holweg and Miemczyk, 2002). With only 32% of UK vehicles made to order (Kiff, 1997; Williams, 1999), Williams (2000) suggests there is a consequence to carrying large stock of finished vehicles and research has found 25% of customers did not receive the exact specification they originally asked for (ICDP, 2000).

Other significant findings from the 3DC project suggest vehicle manufacturers (VMs) have now optimised processes within the factory at the cost of the overall supply chain efficiency Holweg (2003). This is evident by the low stock levels kept by VMs in their factories as well as at the inbound and outbound operations (Holweg and Miemczyk, 2002; 2003; Miemczyk and Holweg, 2004) with the majority of inventory being carried by the first tier suppliers at the very start of the supply chain and in new vehicle stocks held in the market place (*cf.* Figure 8) (Holweg, 2002).

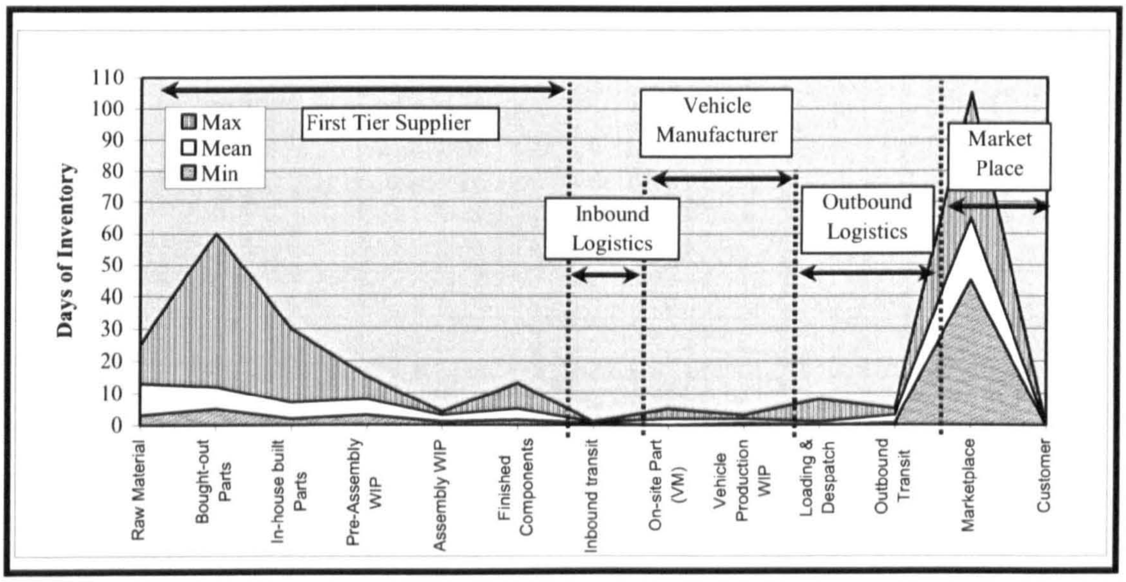

Figure 8: Stock Levels Across Automotive Supply Chain (Holweg, 2002)

Overall the findings from the 3DC project suggest the current new car supply system needs radical reform dependent on major change in capabilities and culture. Taking a more holistic approach, a paradigm shift is needed to focus on customer driven demand rather than building vehicles to stock (ICDP, 2001). In Table 7 the Author summarises some of the paradigm shifts required to deliver a built-to-order car based on the findings from the 3DayCar project.

Existing Paradigm	BTO Paradigm
Closed book financial contracts between players	Open book financial contracts between players
Production stabilised by making to stock	Production stabilised by managing demand
Daily updates of information systems	Accurate & transparent information flow in real time
Silo mentality creating islands of isolation	Holistic view of value chain
Complex designs inhibiting flexibility of manufacture	Design for build to order manufacturing
Variability fixed at the start of manufacturing process	Achieve consumer choice through variety in final assembly
Focus on shifting stock	Focus on selling production slots
Efficiency through lean production	Efficiency & effectiveness through strategic lean thinking
Make to stock	Build to order

Table 7: Paradigm Shifts Required to Delivering a BTO Vehicle

3.4 Conclusion

Six-sigma and in particular the DMAIC cycle has been introduced as useful framework for developing a value improvement model. Lean has been introduced as a useful philosophy for understanding and maximising value in repetitive processes. The following Chapters discuss the development of a value improvement model for repetitive processes using this framework and philosophy to provide valid and reliable research in support of the thesis.

Chapter 4: Review of 5S[15]

4.1 Introduction

Developing a conceptual framework for value improvement, this Chapter is based upon a peer reviewed paper (double blind) presented at, and published in the conference proceedings for the Third International Conference on Six-Sigma held at Strathclyde University in December 2008 (Gibbons, 2008a).

4.2 Background to Research & Introduction to 5S

This chapter of the thesis sets out to introduce the effectiveness of the Japanese 5S system as a steady state platform for future lean and/or six-sigma implementations. The 5S concept derives from a Japanese system for organising people, plant, processes and products. However, typically 5S has been adopted in the West to represent a method of achieving high levels of housekeeping (Kobashi *et al.*, 2008). In this Chapter the argument is made that 5S is much more than a method for keeping the workplace clean. Using findings from six case studies complemented by a taxonomic review of the contemporary 5S literature, a model of 5S deployment is suggested identifying the critical success factors to 5S implementation. Developing a conceptual framework for guiding future research, the model presented argues sustainable business improvements can be achieved through the antecedent implementation of the 5S system.

The 5S concept introduces a five stage process to achieving very high levels of efficiency and effectiveness for plant, people, processes and products: -

1. *Seiri:* roughly translated means to sort,
2. *Seiton:* roughly translated means to straighten,
3. *Seiso:* roughly translated means to scrub,
4. *Seiketsu:* roughly translated means to standardise,
5. *Shitsuke:* roughly translated means to sustain.

[15] Interestingly, long before the author became aware of 5S and it was well known in the UK, he remembers the college workshop he attended as an apprentice engineer being set out using 5S principles with shadow boards for tools and respect for the equipment, staff and fellow students also being very important, 'cleanliness was next to godliness'. Since being introduced to 5S he has often wondered if there is a correlation between levels of effectiveness and efficiency as a tradesperson and levels of discipline whether using 5S principles or the ingrained discipline taught at college.

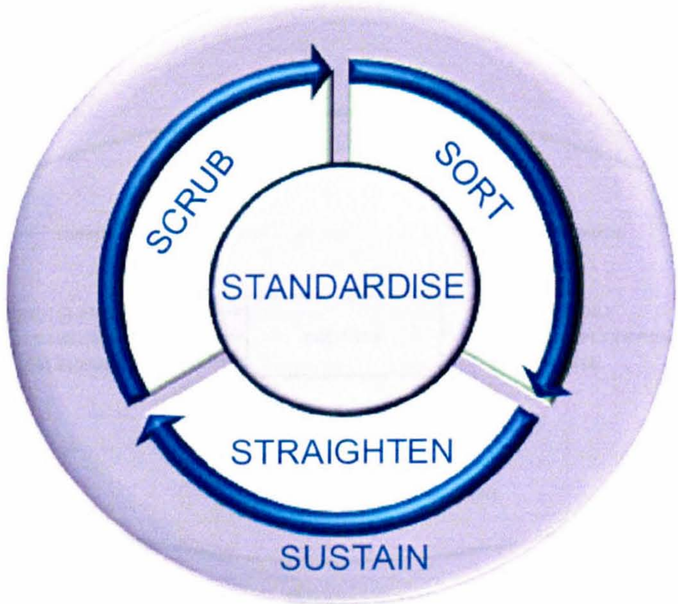

Figure 9: 5S Deployment Model

For achieving a successful deployment of 5S the author argues that rather than being a sequential process working from Seiri through to Shitsuke, a holistic approach is required taking into account the system process inputs and outputs including defining the internal and external system environments as is presented by the Author in Figure 9.

Also critical to a successful 5S deployment is the matching of the hard system elements of the process inputs to Seiri, Seiton & Seiso. In parallel the soft system elements of the process inputs must be matched to Seiketsu. Finally, the overall success of the deployment in seen as dependent on the discipline (Shitsuke) of the human elements to the process.

Attempting to illustrate 5S as a process, the Author presents Figure 10 as a system map representing a typical process showing the human[16], soft system and hard system inputs to the process. The author argues 5S can improve the efficiency and effectiveness of the overall system by correctly organising these inputs to the process so that you may have exactly:

- What you want
- When you want it

[16] The Author makes a distinction between human and soft systems with soft systems being the explicit or implicit procedures followed to complete a process.

- Where you want it
- How you want it

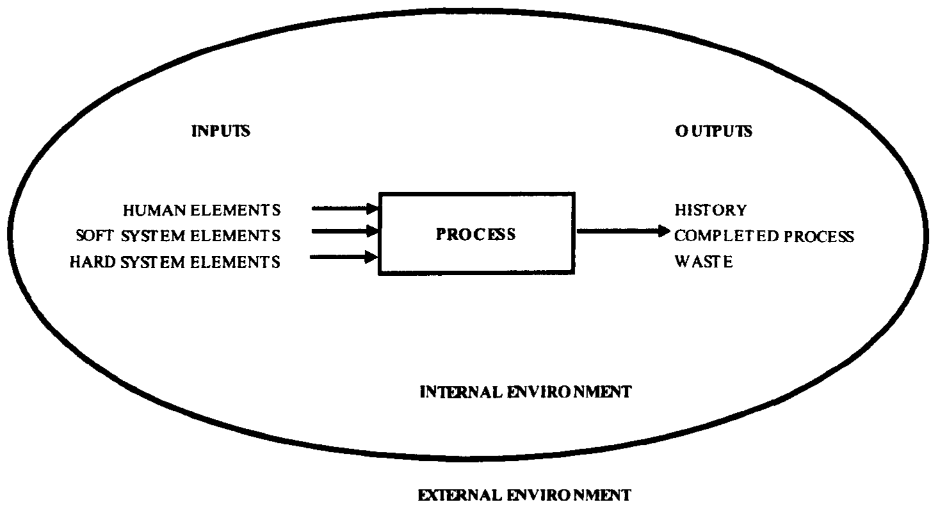

Figure 10: Systems Map of 5S Deployment

The background for the research project comes from the author's own experience of working in operations management in particular the contrasting experience of working for both a Japanese automotive manufacturer and typical (non Japanese) UK manufacturers and service industry providers.

4.3 5S Literature Review

4.3.1 Why Do We Need 5S?

Continuous improvement is defined by Bessant (1992) as an organisational innovation requiring the mobilisation and commitment of all employees in the firm to continually improve the products and processes. It is a systematic attempt to involve all employees in incremental improvement. The improvements are made in small steps over a long period of time. Antithetically, innovation or radical changes are defined as being short-term, usually a technical breakthrough, being one-off in character & project based and high cost.

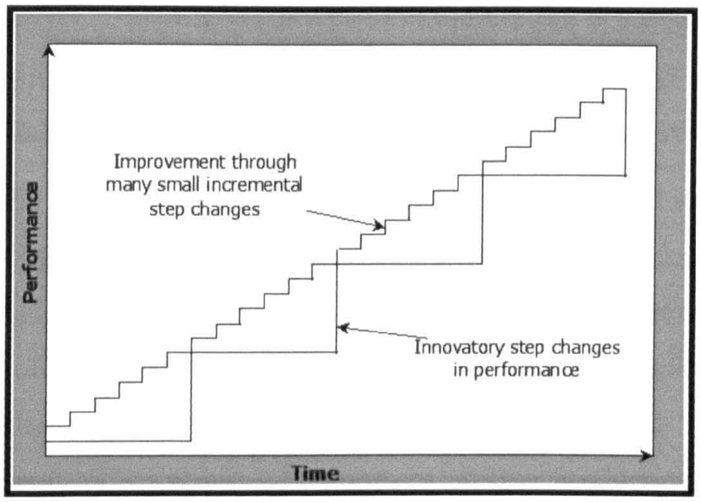

Figure 11: Incremental or Innovatory Improvement

In Figure 11, the Author illustrates the impact on performance over time for both the continuous improvement and innovation strategies. In summary, continuous improvement offers smaller but more frequent improvements in performance and innovation offers much larger improvements in performance but less frequently.

Figure 12: Kaizen Umbrella (Imai, 1986)

In Japan, continuous improvement is translated and defined as Kaizen (Bicheno, 1999). Imai (1986) argues '*Kaizen is simply an umbrella concept covering most of the Japanese practices that have recently achieved world-wide fame'*. Figure 12 shows this vision of Kaizen with a sample of Japanese improvement activities making up the stem of the umbrella (Imai, 1986). From the authors own perspective, Kaizen is often used incorrectly in the UK using the name Kaizen to make unsustainable changes (under the guise of lean) to processes in a short period of time, actually resulting in negative consequences to the process where the intervention was made therefore, linking to the criticisms of lean discussed in the previous chapter.

One of the improvement activities identified under the Kaizen umbrella is Total Productive Maintenance (TPM). Robinson & Ginder (1995) explain the history of TPM as it having its beginnings at a Toyota sub-contractors factory in Japan. The Japan Institute of Plant Maintenance absorbed the main principles and began spreading it to other Japanese factories. Miyake *et al.* (1995) define TPM as a tool to maximize the overall effectiveness of equipment used in production. It is also used to:

> *"transfer a great number of maintenance-related tasks to front-line operators, overthrowing the myth that dealing with 'too complex' equipment is an exclusive competence of the well qualified experts in the maintenance department".*

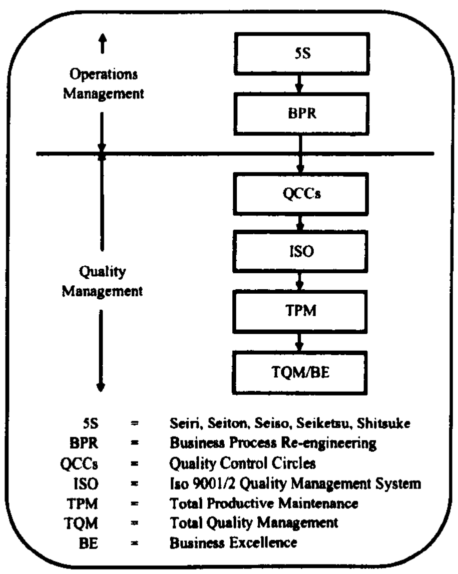

Figure 13: TQMEX Model (Ho, 1999)

Ho (1999) argues the first stage of any implementation of TPM is to successfully implement the 5S. Operationalising the theory to incorporate other improvement initiatives, Ho (1999) introduces a TQMEX model detailing the sequential stages required to successfully achieve Business Process Re-engineering, Quality Control Circles, ISO 9001/2 TQM and TPM (*cf.* Figure 13)

Focusing in on the 5S conceptual framework, in Table 8 the Author presents a summary of published definitions of translations to the original Japanese 5S Romaji[17] words.

Author	Seiri	Seiton	Seiso	Seiketsu	Shitsuke
Hirano (1995)	Organization	Orderliness	Cleanliness	Standardized cleanup	Discipline
Ho (1999)	Organization	Neatness	Cleaning	Standardization	Discipline
Osada (1991)	Organization	Neatness	Cleaning	Standardization	Discipline
Laria etal (1999)	Sort	Organize	Clean	Standardize	Sustaining
Sekine & Arai (1998)	Organization	Orderliness	Cleanliness	Standardized clean-up	Discipline
Hartmann (1992)	Organization	Tidiness	Purity	Cleanliness	Discipline
Lapa (1998)	Sorting	Systematizing	Sweeping	Sanitizing	Self-discipline
Bicheno (1998)	Sort	Straighten	Scrub	Standardise	Self-discipline
Peterson & Smith (1998)	Organization	Neatness	Cleaning	Standardization	Discipline
Imai (1997)	Sort	Straighten	Scrub	Systematize	Standardize
Prod. Press (1996)	Sort	Set in order	Shine	Standardize	Sustain
Chu (1999)	Housekeeping	Organization	Cleanup	Cleanliness	Discipline

Table 8: 5S Literature Translations

Table 8 indicates there is a consensus to published definitions of the five different stages to the 5S system with the only differences evident being minor, or the use of a similar word with roughly the same meaning. However, at this stage a more detailed review of the individual stages to 5S will provide focus and explanation to the capabilities as a foundation for lean and six-sigma deployment.

First S: Seiri

The first step in the 5S system is 'Seiri'. Translated into English it means to sort or to organize (Laraia *et al.*, 1999). The idea is simply to sort out what is needed from what is not needed, and to then discard what is not needed (Ho, 1999). Peterson and Smith (1998) suggest this is best done by placing red tags on items that are possibly no longer needed. The items are logged and then placed in a holding area

[17] Romaji is the application of the Latin alphabet to write Japanese in a way that non-Japanese can read. Japanese is normally written using 'Kanji' logographic characters or the 'Kana' syllabic scripts.

for a predetermined length of time before being discarded. This method enables all people concerned a chance to evaluate whether the item is of any use or needs to be discarded.

The outcome from this activity is then the benefit of a reduced inventory of equipment. Hirano and Rubin (1996) concur suggesting a red tag strategy is a simple method for identifying potentially unneeded items in the factory, evaluating their usefulness, and then dealing with them appropriately

When completing a red tag activity Imai (1997) argues sorting can be classified into 2 categories, necessary items and unnecessary items. The unnecessary items should be discarded or removed from the workplace. As has already been discussed in Chapter 3, the removal of waste is a key element of lean manufacturing (Womack and Jones, 1996b).

Second S: Seiton

The next step in the 5S system is Seiton which translated into English means to straighten or orderliness (Sekine and Arai, 1998) . Following on sequentially from the sorting phase, Tonkin (1998) suggests once you have sorted what you need and discarded what you do not need, Seiton is used to:

- Set the workplace in order,
- Assign a separate location for all essential items,
- Make sure the assigned space is self-explanatory so everyone knows what goes where.

Laraia *et al.* (1999) agree suggesting once everything has been sorted out it is time to organize a place for the remaining equipment. Locations for materials should be clearly identified *"from wastebaskets to hand tools to work instructions. The object is to create visual cues to locations, and work flows etc"* (Laraia *et al.*, 1999). Osada (1991) suggests a typical example of Seiton for storing gauges and other instrumentation devices would be a padded shadow board.

The benefits of Seiton relate directly to the seven wastes of lean discussed in Chapter 3 eliminating the 'unnecessary motion' waste in parallel to the removal of 'inappropriate processing'. The benefit of Seiton is therefore to be able to find something with little time wasted searching. For example, one of the best gains will be in process changeovers, shorter set-up times increase machine availability, make the system more responsive to market demand and increase strategic advantage (Shingo, 1981; 1989).

Third S: Seiso

Once all of the waste has been removed and what is left is straightened out, it is then time to clean up what remains (Hirano, 1995). This can be an initial clean up to set the standard required, followed by periodic cleaning to maintain it. According to Osada (1991) cleaning means inspection and can be split into a three step approach:

- Macro (cleaning everything and dealing with overall causes)
- Individual (cleaning specific machines)
- Micro (cleaning specific parts of machines and causes of grime etc are identified and rectified).

Hirano (1995) concurs arguing cleaning is also inspection and machine or equipment breakdowns are frequently caused by age related deteriorations. To prevent an unwanted breakdown Hirano (1995) proposes to use a daily check sheet that highlights any problem areas.

Tangential to the equipment cleanup benefits suggested by Osada (1991) & Hirano (1995) and important in the development of a conceptual framework for 5S deployment for Lean & Six-sigma; Chen & Lu (1998) argue:

> *"employee commitment to continuous quality improvement can only be nurtured in a clean, well organized environment, suggesting the 5S system should be implemented as a starting point for all quality programs".*

Fourth S: Seiketsu

The fourth 'S' Seiketsu translated into English means standardise. Bicheno (1998) advises standardise can only be successfully implemented if the first 3Ss are in place and being maintained. Arguing further, Bicheno (1998) states standardise has its main focus on standardising the processes and then ensuring that those standards are stringently adhered to. This is similar to the workings of Taylor (1911) whose philosophy was to find the one best method of carrying out a task. The method would minimise time and effort, and maximise quality and productivity.

Bicheno (1998) suggests these standards must be in some written or diagrammatic form and never be verbal. The standard should also say what to do when things go wrong not just when things are operating normally. Imai (1986) provides a useful example of a standardised document introducing Standard Operating Procedures (SOPs). SOPs give clear instructions that should be followed exactly to achieve the required outcome. They are in a standard format that is used for all process procedures.

Fifth S: Shitsuke

The fifth and final 'S' is Shitsuke. Lapa (1998) describes it as the evaluation of all the other four 'S' concepts applied into the workplace. Lapa (1998) suggests a complete survey is carried out by the workforce to measure the level of achievement of the first four Ss. Lapa (1998) also outlines some useful criteria for the surveys:

- It is important that all of the evaluations are carried out in a uniform manor around the workplace.
- The frequency of the audit should be clearly defined
- The standard used for measurement should also be clearly defined to avoid unnecessary variation in the results of the audit.

The benefits of this are two-fold, first it gives an indication of the level of 5S being achieved and second it highlights where the areas of improvement are needed.

Sekine and Arai (1998) provide a useful example of a Shitsuke audit template which will be used in this study to measure levels of 5S effectiveness in the case study companies.

4.4 Case Study Results

There are two components to this research problem. First is the practical problem; this is based around the need for having the 5S. It may seem like common sense to use the 5S system, so why can it be difficult to convince people of their need for it? Second, is the theoretical problem; this is simply the best method of implementation. Why is something that seems so simple so difficult to implement? This section presents a summary of the case study findings through the structured interviews and 5S audits completed at six companies. Ensuring anonymity for the 6 companies involved, pseudonyms are used as follows:

1) Company A (Manufacturing SME, 65 employees, precision engineering)
2) Company B (Manufacturing SME, 285 employees, precision engineering)

3) Company C (Manufacturing SME, 180 employees, FMCG[18])
4) Company D (Manufacturing SME, 68 employees, FMCG)
5) Company E (Manufacturing Large Corporation, 450 employees, FMCG)
6) Company F (Manufacturing SME, 15 employees, Architectural Engineering).

4.4.1 5S Audit Results

Table 9 summarises the performance related findings taken from the 5S audits and the structured interviews. To enable a standard 'index' figure to be made for the results shown, the following calculations have been made[19]:

- A financial performance index figure was calculated by the following steps:
  1. Divide the Company profit made by the number of staff (profit made per employee).
  2. Divide the profit made per employee by the Company turnover (ratio of profit per employee to Company turnover).
  3. Finally, multiply by 100 000 to give an index figure for profit made per employee to Company turnover.
- An accident performance index figure was calculated by the following steps:
  1. The number of accidents divided by the number of staff (ratio of accidents to number of staff).
  2. Finally, multiply by a 100 to give an index figure for the accidents per employee.

Company	Number of Staff	Turnover £(M)	Profit £(M)	Number of Accidents	Financial Index	Accident Index	5S Audit Index
Company A	65	2.3	0	10	0	15	83
Company B	285	36	1.8	70	18	25	57
Company C	180	28	1.4	16	28	9	69
Company D	68	N/A	N/A	20	N/A	29	63
Company E	450	42	2.1	160	11	36	61
Company F	15	1.1	0.005	8	30	53	52

Table 9: Case Study Results Summary

[18] FMCG is the acronym used to describe businesses operating in the 'fast moving, consumer goods' market place.
[19] Company D was a new venture and the case study data was collected in the first year of operation so there was not financial information available.

Figure 14 shows the results of a comparison between the 5S audit results and the accident index figure for each company. The companies are put in order of their achievement in the 5S audit, with the highest rated first.

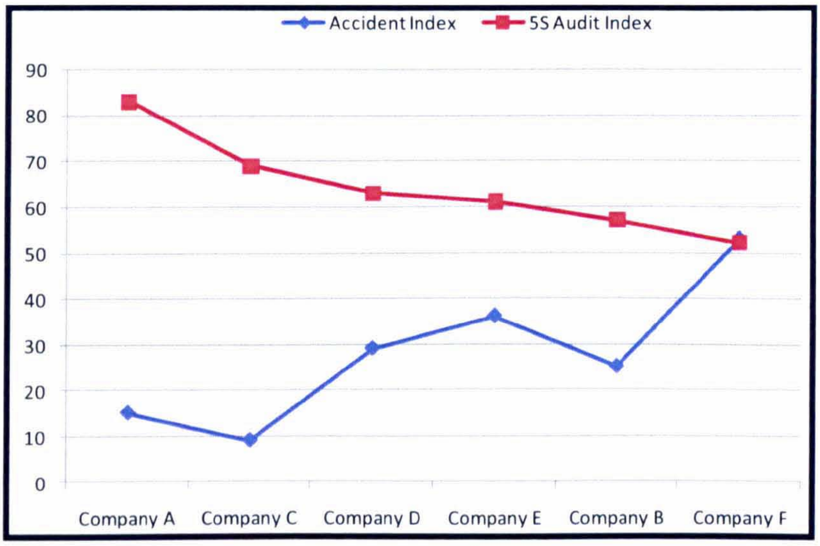

Figure 14: Analysis of 5S Audit to Accident Index

From the data shown in Figure 14 the following inferences are made:

- Company A was rated highest in the 5S audit (index of 83) and had a low number of accidents (index of 15).
- Company F had the lowest rating in the 5S audit (index of 52) and also had the highest frequency of accidents (index of 53).

The result of this simple analysis show there is definitely a pattern showing in the graph, as the level being achieved in the 5S audit reduces, the frequency of accidents increases.

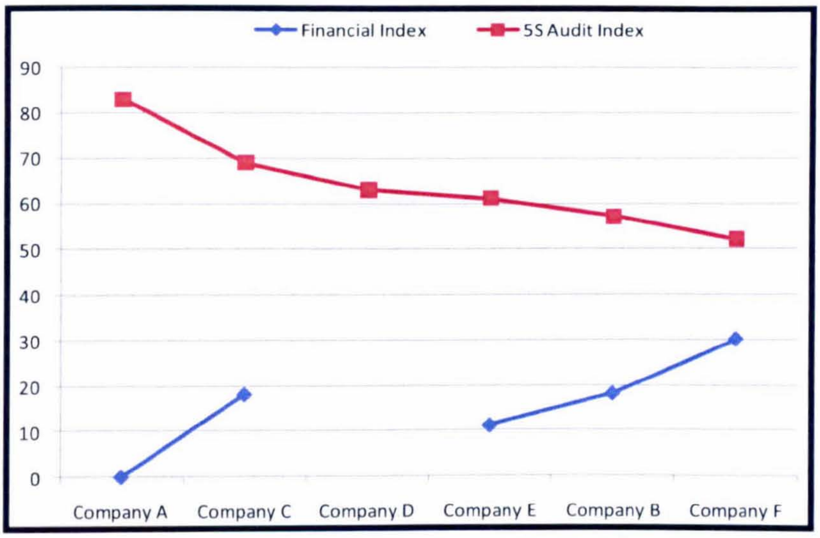

Figure 15: Analysis of 5S Audit to Financial Index

Figure 15 shows the results of a comparison between the 5S audit results and the financial performance index figure for each company. The companies are put in order of their achievement in the 5S audit, with the highest scorer going first. From the data shown in Figure 15 the following inferences are made:

- Company A scored highest in the 5S audit (index of 83) but, did not make any profit[20].
- Company C was rated 2nd highest in the 5S audit (index of 69) and had the 3rd highest profitability index (18).
- Finally, Company F -as the only non 5S company- finished last in the 5S audit (index of 52) however, they had the highest profitability index figure (30).

In comparison to Figure 14, the relationship between profit and levels of 5S is not as clear in Figure 15. For example, although Company A had the lowest profit level, this was because it was a new Company and only operating for just over a year and the first year of business it did not make any profit due to investment costs. Therefore it is difficult to say whether there is a correlation between profit levels and 5S and perhaps future research could look into this in more detail.

4.4.2 Interview results

From the interviews the following summary statements can be made:

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[20] Company A was only in its second year of operation and the financial figures for the first year did not show a profit as was expected in the business plan (due to investment costs).

- Of the companies interviewed 40% had not had any previous process improvement activities. The remaining 60% had all failed in their previous attempts at a process improvement activity.
- The driving force for the 5S had come from the management team in five out of the six companies, the other coming from the engineering department.
- The response from the workforce was generally quite negative from the companies where previous implementation projects had failed. In the two new companies the workforce were more positive and saw the 5S as a worthwhile venture.
- All of the training was given away from the work place and in classrooms except at Company D, where the training was given on-the-job. The normal duration for a training session was one day.
- Once the training had been completed all of the companies set up implementation teams and went through the 5Ss sequentially. At Company D the team decided to set up a pilot area whereas the other companies implemented company wide.
- The reasons for companies implementing the 5S were split into 2 categories. First, 40% were doing it to have a cleaner/tidier factory. Second, 60% were doing it to improve safety, increase productivity as well as for having a cleaner factory.
- 60% of the companies felt the 5S had been or was being successfully implemented into their companies. The rest felt that it could have been implemented successfully if a different method was used.
- All of the companies felt that commitment at management as well as shop floor levels were needed to successfully implement the 5Ss. One of the key failings listed was a lack of discipline from all levels.

The following lists the key elements to 5S implementation, critical success factors to 5S identified from the case study interview feedback:

1. First train all staff in the practical as well as theory elements of 5S
2. Plan implementation around quiet periods of production
3. Have a 5S Champion
4. Make 5S mandatory across the company
5. Use audits in a competitive manner to encourage improvements

6. Have full financial support from budget holders
7. Allow ownership of areas and encourage empowerment to design and sustain
8. Encourage team working
9. Make resources available if needed.

4.5 Discussion

R1. Can 5S be applied as a philosophy for sustained business improvements or is it just a tool for housekeeping in factories specifically on the shop floor?

Similar to the findings of Bayo-Moriones *et al.* (2010) the research findings in this investigation suggest that high levels of 5S can be linked to significant improvements to process performance including safety, quality and productivity. Through the results of this study -as a foundation for lean and six-sigma deployment-the 5S process has been shown to be a useful platform to standardise current processes creating a steady state arena for their successful implementation. This argument is also supported by Kobashi *et al.* (2008) who suggests the key to the Japanese business success after World War II can be traced to the links with 5S as an overall philosophy applicable to both business and personal life and therefore 5S is more than just a tool to be used in factory housekeeping. This link to 5S as a philosophy in Japanese culture is also made by De Mente (1994) who links the cleanliness and order of 5S to Shintoism[21]. Seddon (2005) also links the 5S approach directly to the Japanese language arguing 'sei'[22] in Japanese Romanji means *"to arrange, to create sequence"* and the 5Ss are therefore an intuitive approach to working for Japanese people.

[21] Shintoism is an ancient Japanese religion based on achieving purity through ritualism
[22] 'Sei' is used at the start of the first 4 Ss when using Romanji: Seiri, Seiton, Seiso & Seiketsu

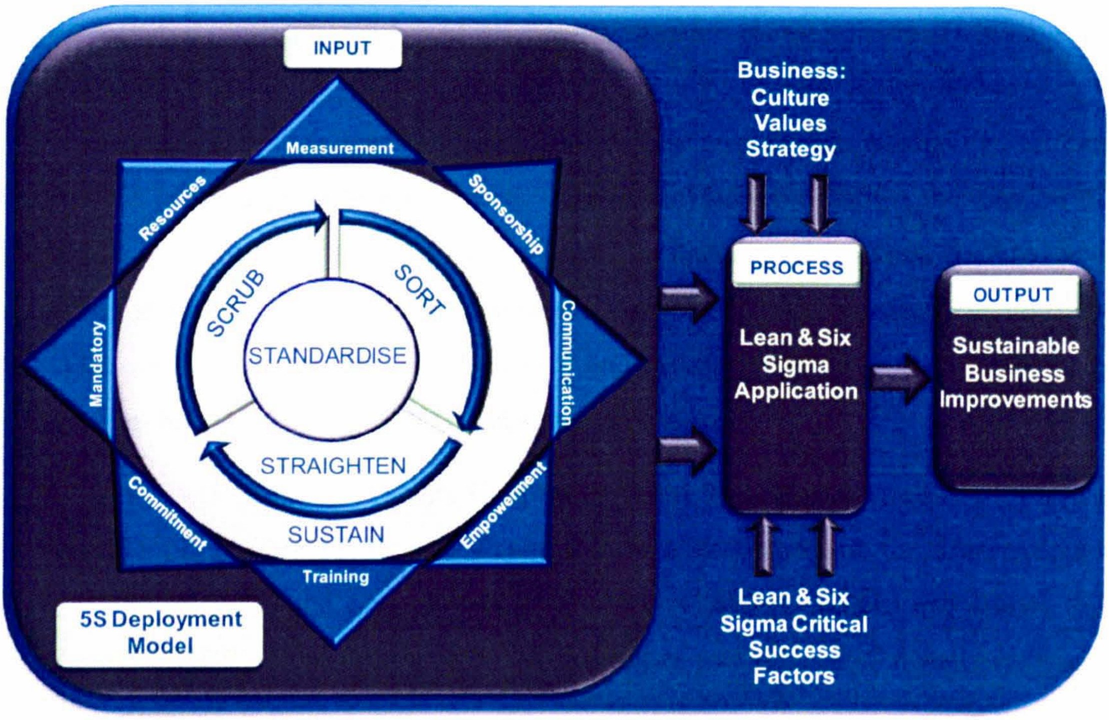

Figure 16: Sustainable Business Improvement Model

Figure 16 presents the Author's proposed model of lean six-sigma implementation and also a model for 5S implementation in its own right. The critical success factors to achieving 5S have been added to the 5S deployment model presented in Figure 9 and the revised model of 5S deployment is shown as a direct input to the lean six-sigma implementation. The model argues sustainable business improvements can be achieved through lean and six-sigma implementation if 5S has been achieved as a prerequisite to build a steady state platform to base any changes to the process on. If this is not extant then any changes made to the process could be based around invalid information possibly negatively influencing the process and subsequently business improvements are not made.

4.6 Conclusion

This chapter has introduced the concept of 5S as an important philosophy for achieving sustainable business improvement and not just a lean tool for improving housekeeping in manufacturing facilities. The introduction of 5S as a philosophy has been deliberately positioned at this point in the thesis as the following chapters will build upon this argument providing specific case study examples of how important 5S is in the development of a value improvement model for repetitive processes.

Chapter 5: Improved Overall Equipment Effectiveness Measure

5.1 Introduction

Developing the conceptual framework further with the knowledge that 5S can and should be used to provide a basis for any improvement initiative, this section of the thesis introduces a useful measure used to understand process performance classified as Overall Equipment Efficiency/Effectiveness[23] (OEE) complementary to 5S. Also introduced is a link between lean and six-sigma through using OEE as a measure in the six-sigma DMAIC improvement process.

The work presented in this Chapter is based around three published papers (all double blind peer reviewed). Paper one was published in the International Journal of Six-sigma and Competitive Advantage (Gibbons, 2006b) and shows the link between OEE and six-sigma. The second paper was presented at and published in the conference proceedings at the 2nd European Research Conference on Continuous Improvement & Lean Six-sigma where it was also awarded the best paper (Gibbons, 2010a). The third paper further expands this conference paper material and was published in the International Journal of Lean Six-sigma (Gibbons and Burgess, 2010) and was also awarded the Frazer Nash Best Paper Award in 2010.

5.2 Critique of OEE

Muchiri and Pintelon (2008) question whether OEE really is a measure of efficiency or effectiveness suggesting individual plant efficiencies can only impact overall business effectiveness when looked at holistically. Arguing further, Muchiri and Pintelon (2008) suggest the manufacturing process is a complex web of interactions where resources must be deployed strategically focusing on the performance of the whole factory not just individual equipment. This is validated further by another criticism where Parida and Kumar (2006) argue OEE -in its original format- is inadequate giving an example where a business can have a high OEE (internal effectiveness) but low customer satisfaction (external effectiveness).

[23] Some practitioners prefer to use efficiency rather than effectiveness but the author will argue later in the Chapter that OEE is a measure of effectiveness made up of 3 individual efficiencies, availability, performance and quality.

The OEE literature is also replete with criticisms of the many different ways in which OEE is calculated (Muchiri and Pintelon, 2008). For example, Raouf (1994) has looked to overcome some of the criticisms of OEE introducing production equipment effectiveness (PEE) as an indicator of capital productivity in continuous process industries. By adding weighting to the individual elements of the OEE calculation a focus can be made on the critical elements of the process being measured such as performance in a continuous process with no set-up times. However, the PEE approach moves away from a standard OEE calculation format removing the opportunity to benchmark between individual pieces of equipment and similar process employed by other businesses. PEE also detracts from the core purpose of OEE which is to understand the total value adding time from the total time available (Nakajima, 1988; 1989).

Other approaches criticise the elimination of planned downtime from the OEE equation suggesting a calendar based approach rather than production schedule will show the true overall plant efficiency (OPE) or total effectiveness equipment performance (TEEP) (Ahuja and Khamba, 2008). The OPE and TEEP measures include planned downtime into the loading time hours with the objective of giving a more holistic view of asset utilisation. TEEP also incorporates indicators of mean time to repair (MTTR) and mean time between failures (MTBF) as part of an unplanned downtime element of the OEE calculation (Muchiri and Pintelon, 2008). However, TEEP is an OEE measure focused on asset management effectiveness alone and does not include other downtime such as machine set-up & adjustment.

Jeong & Phillips (2001) argue OEE as defined by Nakajima (1988) is not suitable for capital-intensive industries where asset utilisation must be calendar based rather than loading time based and introduced the 'total productivity improvement visibility system' (TPIS) as a development of OEE. TPIS incorporates and distinguishes between (in the availability calculation): non-scheduled time; scheduled maintenance; unscheduled maintenance, research & development usage; engineering time as well as the set-up and adjustment times (Jeong and Phillips, 2001).

Other similar developments include overall asset effectiveness (OAE) & overall plant effectiveness (OPE) both with the objective of incorporating calendar based time into the OEE equation giving a quantitative measure of business-level effectiveness (Muchiri and Pintelon, 2008). However, similarly to the PEE approach, the TPIS, OAE & OPE calculation frameworks are all bespoke deviating from a standard OEE calculation framework reducing the opportunities for benchmarking.

This review of the lean, TPM and OEE related literature has introduced the concept of lean and the focus on waste elimination to increase the value-adding elements to a process. The captious review of OEE literature has revealed an abundance of alternative methods of calculating OEE in an attempt to satisfy the needs of businesses that now require a more holistic measure of process and/or asset performance. However, many of these bespoke OEE developments move away from the original framework as presented by Nakajima (1988; 1989) removing the opportunity to use OEE as a benchmarking measure. The ability to compare internal performance against external competition and vice-verse is a critical attribute of any performance measurement system and avoids the problem of short-term thinking and also gives strategic focus (Neely *et al.*, 1995).

5.3 Improved OEE Measure

Focusing on the Total Productive Maintenance (TPM) element of the lean framework proposed by Hines *et al.* (2004) also introduced under the kaizen umbrella proposed by Imai (1986), Robinson & Ginder (1995) introduce TPM as maintenance management initiative with origins at a Toyota sub-contractors factory in Japan. The Japan Institute of Plant Maintenance -launched in 1981 (JIPM, 2010)- absorbed the main principles from this factory initiative and began spreading the approach to other Japanese factories. Miyake *et al.* (1995) define TPM as a tool to maximize OEE as well:

> *"transfer a great number of maintenance-related tasks to front-line operators, overthrowing the myth that dealing with 'too complex' equipment is an exclusive competence of the well qualified experts in the maintenance department".*

Nakajima (1988; 1989) introduces OEE as the measure of TPM used for collecting and analysing the combined effects of plant availability, performance and quality. Edward & Hartmann (1992) propose that within most plants there is a hidden factory offering some 25-30% more capacity; they suggest TPM is the key that can unlock the hidden factory and OEE is the measure that allows a calculation to be made of the current equipment efficiency and more importantly the improvement potential within the equipment. This is confirmed by Willmott & McCarthy (2000) who suggest that by combining the best individual results for availability, performance and quality, the proven potential of the equipment can be calculated and the best-of-the-best OEE can be known.

Robinson & Ginder (1995) define OEE as a measure of the effective utilisation of capital assets by expressing the impact of equipment losses based on seven types of equipment losses tracked in the OEE calculation:-

1. Downtime due to machine breakdown
2. Time required for set-up and adjustments
3. Time or cycles lost to inefficient start-up
4. Time or cycles lost to tooling
5. Time or cycles lost to minor stoppages
6. Operating at less than ideal speed
7. Producing defective or off-spec product that is rejected, requires rework or repair, or is sold at a lower price.

Sekine & Arai (1998) re-categorise the seven equipment losses into the three elements of the OEE calculation. Losses 1-4 are covered by plant availability; losses 5 & 6 are covered by plant/process performance; and loss 7 is covered by process quality. Figure 17 shows an example of the OEE as suggested by Braglia *et al.* (2009) adapted to illustrate the decreasing efficiency cycle that is the basis of the OEE calculation.

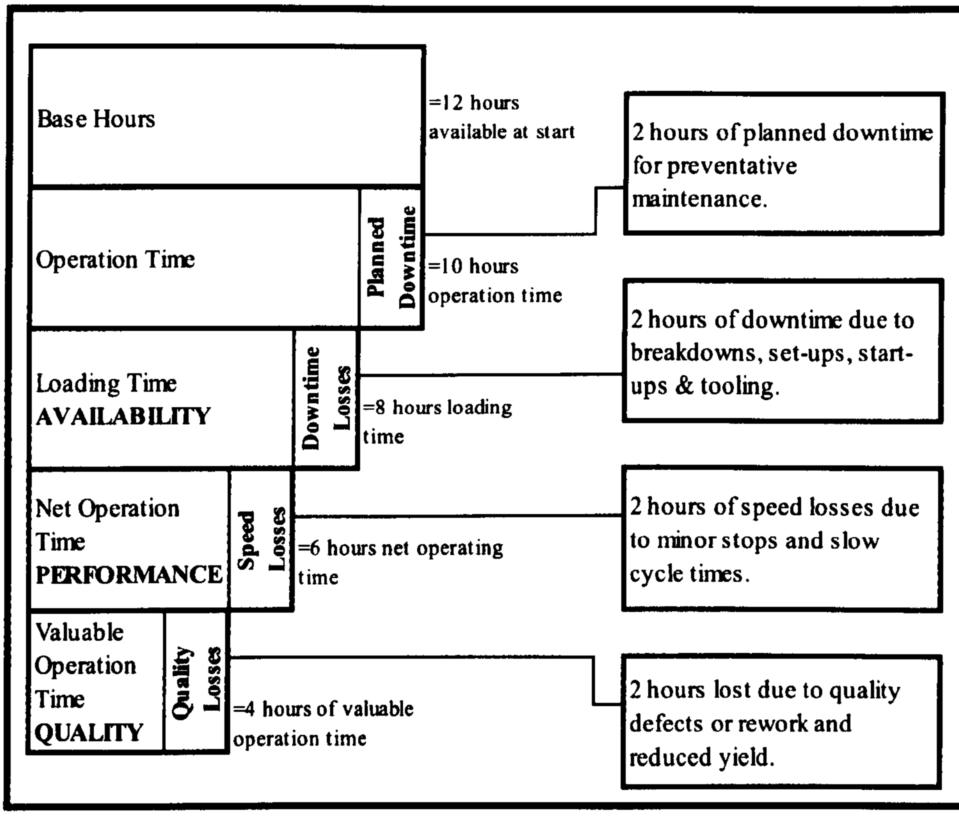

Figure 17: OEE Calculation Table (Braglia *et al.*, 2009)

In the OEE table example presented in Figure 17 there are 12 hours available at the start which is classified as the 'Base Hours'. From the base hours, 2 hours have been deducted due to planned maintenance. This, or any other planned downtime, is not included in the OEE calculation as the focus is on understanding the effectiveness of the plant when it is planned to run. The 'Operation Time' has now been set and the OEE can now be calculated as follows: -

Of the 10 hours left, 2 hours is lost due to downtime on the machine such as changeovers and breakdowns.

$$Availability = 8hours/10hours = 0.8 = 80\% \quad (1)$$

Of the 8 hours the machine was run, 2 hours were lost due to minor stoppages and a slow cycle time.

$$Performance = 6hours/8hours = 0.75 = 75\% \quad (2)$$

Of the 6 hours of output from the net operating time, 2 hours were lost due to rejects or rework.

$$Quality = 4hours/6hours = 0.66 = 66\% \quad (3)$$

From the availability, performance and quality calculations, the OEE can now be calculated.

$$OEE = availability \times performance \times quality$$

$$= 0.8 \times 0.75 \times 0.66 = 0.40 = 40\% \quad (4)$$

The resultant OEE is therefore 40%, or 4 hours value adding time from the 10 hours of plant operation and 12 hours of actual time available (if there was no planned down time).

5.4 DMAIC Case Study Example

5.4.1 Case Study Background

The following introduction to using OEE as a measure in the six-sigma DMAIC improvement approach is based around a single study carried out by the Author in a manufacturing plant specialising in plastic processing where there is known to be higher than expected production reject levels and high levels of material wastage.

5.4.2 Define

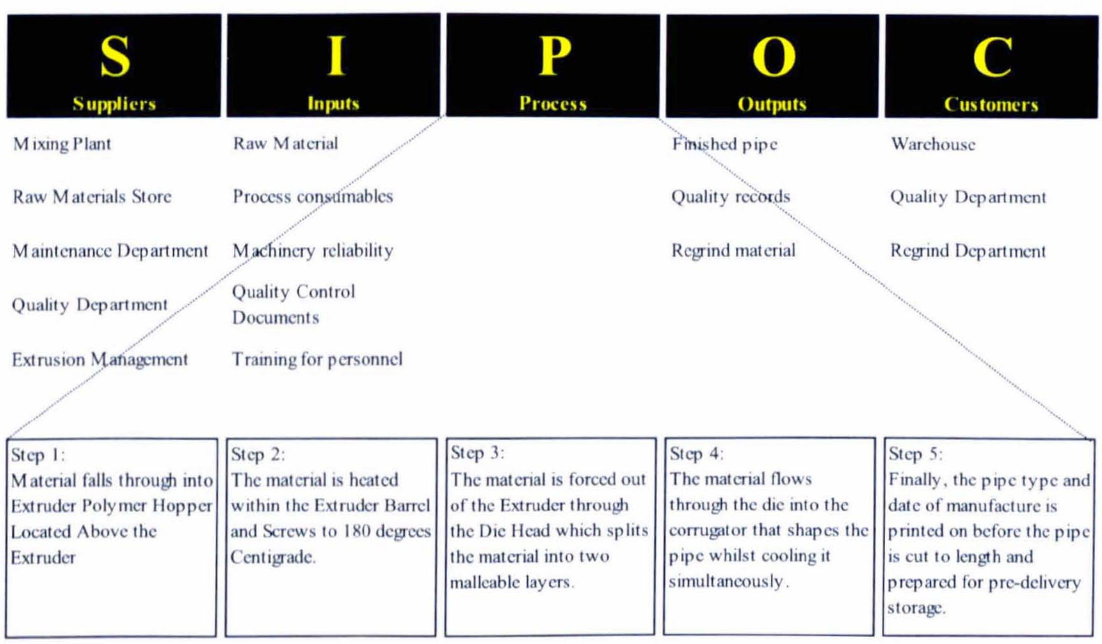

Figure 18: Extrusion Process SIPOC

Figure 18 shows the Author's proposed SIPOC for this process setting the scope of the investigation and indentifying the key customers, their requirement specified under outcomes and the suppliers and their inputs to the process summarised to the five main steps. Any other activities outside of these process steps are not included inside the scope[24].

The project charter for this case study process improvement was established using the following format suggested by Pande & Holpp (2002): -

- *A business case: Why is this particular opportunity being chosen?*
  The business case for the improvement is the need to reduce wastes within the process to improve overall equipment effectiveness in-line with customer price cut demands and business overhead cost increases.
- *Problem/opportunity and goal statement: What's the specific problem or pain being addressed, and what results will be sought?*
  The problem/opportunity for the process has been identified as the amount of regrind being generated. One process alone has transformed over £1m of virgin material into regrind in the last 6 years. The target is to reduce the current regrind generation by 5% overall without reducing the overall equipment effectiveness.
- *Constraints/assumptions: What limitations are placed on the project or resource expectations being made?*
  The constraints of the process can be defined as there must be minimal impact to the ongoing manufacturing during the project. The plant and its machine operators are all to be involved whilst ensuring the plant is run to plan, usually 24 hours a day, seven days a week. Subsequently, the main constraint is the ability to get all of the team together in one room at the same time, the machine operators follow a 4 shift pattern with 4 different shift crews who never meet together and only communicate during shift changeover.
- *Scope: How much of the process and/or range of issues are "in bounds"?*
  The project scope will only deal with the plant, methods, tools and personnel within the process under investigation at all the steps between the extruder

[24] The author feels this could be a critical failure in the six sigma methodology as improvements are based round activities within the scope of the SIPOC without fully understanding the process more holistically. The value improvement model development discussed later in this thesis seeks to overcome this 'silo' approach to process improvement.

heating and extruding the polymer to the final stacking of the pipe in the stacker. Any raw material issues are outside the scope of the project.

- *Players and roles: Who are the team members, champion and other stakeholders?*

  For the project the champion has been defined as the extrusion factory manager, the shift crews as the improvement team members, and the author as the technical expert and facilitator.

5.4.3 Measure

Data Collection Methodology: Management Implications[25]

For the research carried out in this improvement initiative the author would like to add one more critical success factor to the list presented by Basu (2004) in Chapter 3, the buy-in from the shop floor personnel. Yes, six-sigma is a well structured, objective and quantitative based approach that can be used to improve a business, but, obtaining the buy-in from the people being mostly affected by the change is often overlooked and may be the reason why six-sigma sometimes fails to deliver sustained improvements. From a research ontology (Benton and Craib, 2001) and epistemology (Johnson and Duberley, 2000) standpoint, six-sigma could be classified as objectivist and positivistic due to its dependence on quantitative data. However, when dealing with people, to gain buy-in to a project, a more qualitative (Silverman, 1997; Bryman and Bell, 2003) approach should be adopted which can be classified as constructionist and interpretist, the antonym of the objectivist and positivist standpoints. The constructionist standpoint assumes that people are not robots and their perpetual social interactions lead to a view of social reality that is in a continual state of flux; the interpretist standpoint assumes the creation of knowledge does not come solely from the application of the methods used in the natural science model of research. Therefore the ideal epistemological standpoint for six-sigma research should possibly adopt a critical realist (Bhaskar, 1975) approach which combines elements of positivism and interpretivism encompassed in a triangulated (Jick, 1979), qualitative and quantitative strategy.

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[25]Developing a robust data collection system is critical to the success of any improvement project and this extended discussion is important to understand the management implications for this and any process improvement activity. Also, the elements discussed in this section will also be developed further as some of the internal influencing factors of the value improvement model presented in Chapter 8.

The argument for gaining buy-in from the personnel involved in change is made by Shingo (1989) who states that:

"more important than anything else is securing the understanding and consent of everyone in the plant, especially of the people on the shop floor. Indeed that is the key point that will determine success or failure".

This also confirms Hyclak and Kolchin's (1994) view that the benefits to a company are twofold if they include the workers in the decision making positions. First they argue that involvement offsets workforce resistance to change and secondly, they argue that worker participation in the system design process promises to:

"speed-up the "phasing-in" period by taking explicit advantage of the worker's unique storage of knowledge about the work process".

This is validated by Antony (2000) who argues that the plant operators know the process better than anybody else and are also in the best position to see the contributors to poor process efficiency. Hill (1991) also argues that the workforce involvement is critical if the company is to fulfil their requirements of an improvement project. He also generalizes about the failure of UK manufacturing companies to recognize the value of shop floor personnel contributing to continuous improvement.

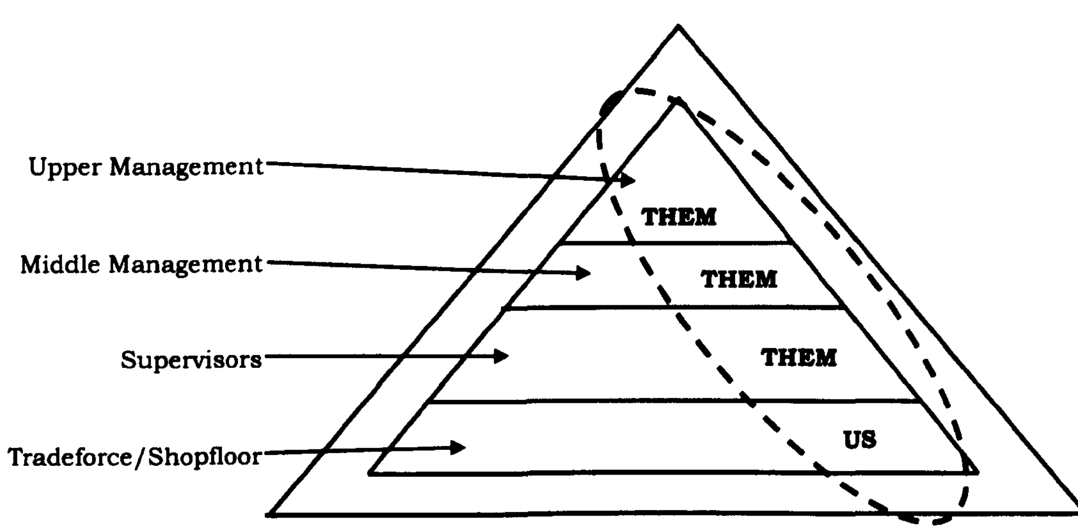

Figure 19: Vertical Polarisation (Kelly, 2001)

Kelly (2001) explains that sometimes there exists a vertical polarisation[26], a build up of a conflict in attitudes, objectives and communication between the shop floor and different management levels. Figure 19 shows Kelly's model of vertical polarisation with the shop floor represented as 'us', and the different levels of management represented as 'them'.

Turbide (1995) argues that it is not uncommon for the workforce to stand in the way of new technologies. He gives an example to back up the argument where a group of machine operators were asked to take responsibility for the care and routine maintenance of their equipment and workspace. The response was negative and succinct, *"I operate the machines, and someone else fixes them!"* The response he was looking for would have been *"I am responsible for my own equipment"*. This also concurs with Kelly's perpendicular to vertical polarisation, horizontal polarisation. Kelly (2001) defines horizontal polarisation as the conflict that occurs across the maintenance and production interface or between the various groups or departments in an organisation – a conflict of attitudes and communications. He goes on to say that this can lead to the entrenched view that *"they (the operators) bust the plant; we (the maintainers) fix it"*. Figure 20 shows Kelly's model of horizontal polarisation with the various organisational departments represented as 'them' and the team undergoing the change represented as 'us'.

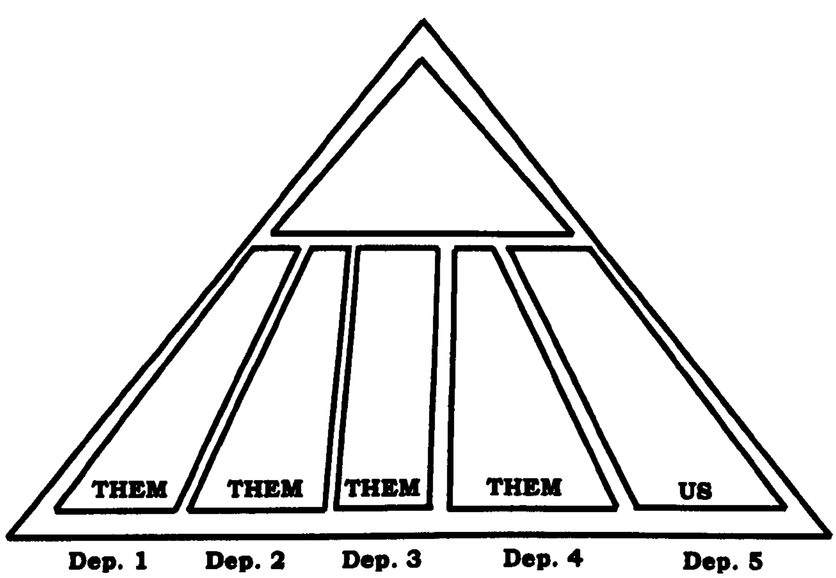

Figure 20: Horizontal Polarisation (Kelly, 2001)

[26] The following chapter develops the concept of polarisation further based on this definition presented by Kelly.

When implementing a change programme such as a six-sigma project, it is therefore important to involve people vertically, for example: plant operators; their supervisors; line managers and factory managers etc. It is also important to involve people horizontally, for example: the department undergoing change and the different departments that interface with them. Welch & Byrne (2001) call this approach *"boundaryless collaboration"* and Pande *et al.* (2000) define it as *"the breaking down of barriers to improve teamwork, up, down and across the organizational lines"*. Boundarylessness was a key business objective of Jack Welch the former chairman of General Electric.

Ginder & DeLozier (1996) suggest a methodology of thinking that leads to a win for the person implementing change, a win for the people affected by the change and a win for the business involved in the change. Knight (2002) explains their methodology as a balanced approach to implementing change taking into account three primary perspectives: -

1, *Own shoes*, look at the situation from the implementer's position and ask, what do I want, what is important to me from this change?

2, *Their shoes*, the implementer puts themselves in the shoes of the people affected by the change. Not just to think what it is like to be in their shoes but actually to experience the situation as the people undergoing the change.

3, *Observer*, stand back and experience the situation as a detached observer, as a fly on a wall looking down on the activities to relate them to the business as a whole.

Perhaps a lack of this type of thinking is one reason for failures in six-sigma projects; it covers both the macro and micro levels suggested by De Feo & Barnard (2004) and can be easily related to all of the critical success factors suggested by Basu (2004).

Data Collection Methodology

To collect the raw data on the process a new shift data log was required as the existing one only captured the total output and rejects per shift with no other details. Taking into account the previous discussion about gaining buy-in from the shop floor, the shift log was developed involving personnel up and across the business and the three perspectives suggested by Knight (2002) were taken into account.

Team meetings were held involving personnel from production, engineering, planning and management. During the meetings the background behind the need to change and the methodology to be used were introduced. Stepping into their shoes to better explain OEE and DMAIC etc, the meeting attendees were split into two mixed teams to participate in various exercises. The team population was all male aged between 30 to 55 years old. Exercises based around improving their fishing were used to metaphorically introduce the benefits of the process they were undertaking. It worked so well that some of the team actually used the OEE principles to improve their fishing and the metaphor was therefore used throughout the DMAIC cycle.

	Code	Details
SETTER	S1	Waiting setter
	S2	Length change
	S3	Die strip and clean
	S4	Set/adjust printer
	S5	Line changeover
	S6	Start-up period
	S7	Setter adjustment
QUALITY	Q1	Quality Test Sample
	Q2	Socket out of spec
	Q3	Socket delamination
	Q4	Wall thickness out of specification
	Q5	Burn marks on pipe
	Q6	Print out of specification
	Q7	Blown Corrugation
	Q8	Mismatch on pipe
	Q9	Corrugation alignment
	Q10	Failed impact test
	Q11	Failed 'Stis' test
	Q12	Failed Reversion test
MAINTENANCE	M1	Maintenance working on extruder
	M2	Maintenance working on corrugator
	M3	Maintenance working on saw
	M4	Maintenance working on stacker
	M5	Maintenance working on mixomat
	M6	Planned Maintenance
	M7	Maintenance working on printer
OTHER	A1	No Programme
	A2	No Operator
	A3	Waiting Material
	A4	Waiting Toolroom

Table 10: OEE Data Collection Failure Modes

Once the team had a good understanding of the requirements of the shift log, based on the team exercises, downtime codes were adopted to simplify the recording process. As has already been discussed, the downtime codes used could only be defined by the machine operators; as Antony (2000) suggests, they know the process better than anybody else and are in the best position to see the contributors to poor process availability, performance and quality. Table 10 details the codes agreed by the team to be used in conjunction with the shift log sheet as developed by the Author.

Using the shift log, data was collected over a six-week period with a view to carrying out a post-improvement six-week measurement for comparison. As Hoerl (2004) suggests, *"Six-sigma projects should be doable in 3-4 months"*.

5.4.4 Analyse

OEE has many different applications including providing data:

- For those failures that are plant specific such as a real-time KPI calculated on the shop floor by machine operators during their shift;
- as an indicator of the best-of-the-best OEE showing the plant potential. For managers, simple analysis would show which shifts, if any, perform better based on their OEE.

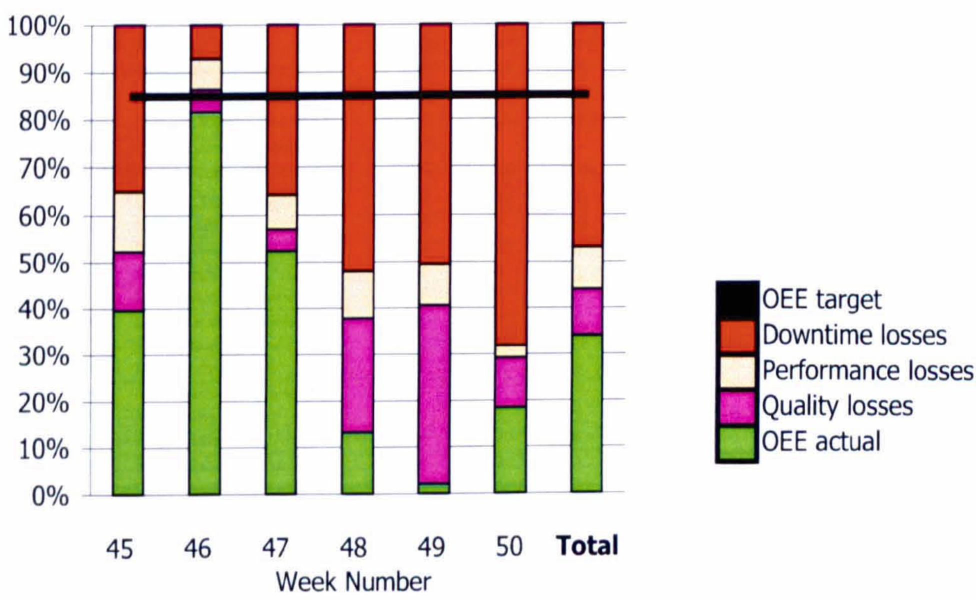

Figure 21: Initial OEE Results

For the purpose of the DMAIC process there is one use which could possibly eliminate the need for Failure Mode & Effects Analysis (FMEA). Snee (2004) suggests that the FMEA is a *"disciplined methodology for identifying potential process defects"*. The word potential suggests not proven, the data captured in OEE is proven and not based on subjective decisions as FMEAs can be.

Figure 21 shows the OEE results for the initial six week measurement period as presented by the Author. The downtime, performance and quality losses are represented in the block graph as is the actual OEE achieved. Simple visual analysis shows that there is considerable room for improvement but how and where? The where can be identified from the raw data collected in the shift logs and the how can be achieved by eliminating it.

			Week Number						
			45	46	47	48	49	50	Total
Loading Time	A	Standard hours available	8640	10080	10080	10080	10080	10080	59040
	B	Planned Downtime	0	0	0	0	0	0	0
	C=A - B	Loading Time	8640	10080	10080	10080	10080	10080	59040
Availability	S1	Waiting setter	0	420	1980	4660	2160	4380	13600
	S2	Length change	0	60	0	0	0	0	60
	S3	Die strip and clean	930	0	1050	1470	210	2960	6620
	S4	Set/adjust printer	0	0	0	0	0	0	0
	S5	Line changeover	1290	210	0	0	600	0	2100
	S6	Start-up period	900	0	240	1110	330	470	3050
	M1	Maintenance on extruder	0	0	540	330	0	0	870
	M2	Maintenance on corrugator	120	0	0	60	90	75	345
	M3	Maintenance on saw	0	11	0	30	0	15	56
	M4	Maintenance on stacker	0	0	0	0	0	0	0
	M5	Maintenance on mixomat	0	60	105	0	0	0	165
	M6	Planned Maintenance	0	0	0	0	0	0	0
	M7	Maintenance on printer	0	0	0	0	0	0	0
	A1	No Programme	0	0	0	0	5880	0	5880
	A2	No Operator	570	0	0	0	0	0	570
	A3	Waiting Material	0	0	120	0	0	0	120
	A4	Waiting Toolroom	0	0	0	0	0	0	0
	D	Total Downtime	3810	761	4035	7660	9270	7900	33436
	E=C - D	Running Time	4830	9319	6045	2420	810	2180	25604
	F=(C-D)/C	Downtime Efficiency	56%	92%	60%	24%	8%	22%	43%
Performance	S7	Setter adjustment	650	185	304	375	270	2401	4185
	G	Output (total parts made)	841	2024	1446	515	126	726	5678
	H	Cycle Time (minutes)							
	I = GxH/E	Performance Efficiency	84%	93%	92%	85%	84%	97%	89%
Quality	Q1	Quality Test Sample	20	26	12	4	0	6	68
	Q2	Socket out of spec	75	7	24	0	21	42	169
	Q3	Socket delamination	36	14	20	123	0	0	193
	Q4	Wall thickness	0	0	0	0	0	0	0
	Q5	Burn marks on pipe	0	0	0	0	0	7	7
	Q6	Print out of specification	0	0	0	0	0	0	0
	Q7	Blown Corrugation	1	53	18	57	67	35	231
	Q8	Mismatch on pipe	0	0	0	0	0	0	0
	Q9	Corrugation alignment	0	4	0	0	0	0	4
	Q10	Failed impact test	0	0	0	0	0	0	0
	Q11	Failed 'Stis' test	0	0	0	0	0	0	0
	Q12	Failed Reversion test	0	0	0	0	0	0	0
	J	Total lost Quality	132	104	74	184	88	90	672
	K=(G-J)/G	Quality	84%	95%	95%	64%	30%	88%	88%
OEE	L = FxIxK	Overall Equipment Efficiency	40%	82%	52%	13%	2%	18%	34%

Table 11: Initial OEE Raw Data

Table 11 shows the data collected from the initial six-week study as presented by the Author. Using the Pareto principle the data in the total column can be analysed to show which of the downtime or quality codes is creating the greatest inefficiency. Figure 22 shows the quality losses Pareto analysis graph with a cumulative percentage line added as presented by the Author. Drawn on to the graph is an 80% cumulative block that helps indicate that 2 - 3 of the 12 (roughly 21%) failure mode categories, Q7 (blown corrugation), Q3 (socket de-lamination) and Q2 (socket out of specification), represent 80 - 90% of the total failures recorded over the six-week period. Using the cumulative line it is worth pointing out that over 99% of the failures fall within 4 of the 12 quality inefficiency failure modes. These 4 failure modes, especially Q7, Q3 & Q2, should be investigated further to identify the root causes before any improvement initiative is implemented. It would not, at this stage, be worth spending any time on trying to improve the failure modes, Q4, Q5, Q8, Q10, Q11 & Q12 as there has been no pipe failures recorded for these failure modes.

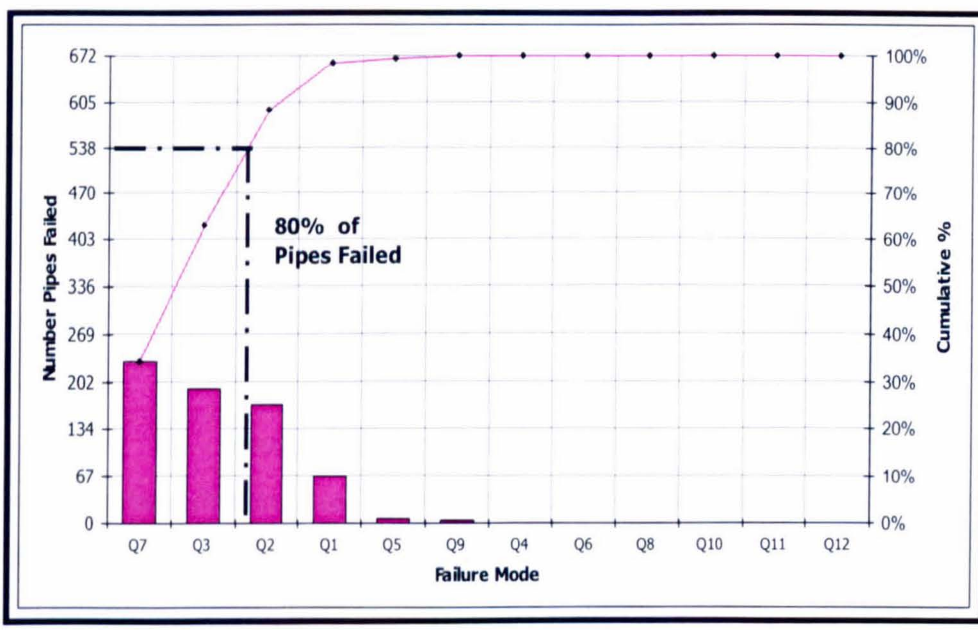

Figure 22: OEE Data Quality Failure Mode Pareto Analysis

5.4.5 Improve

The improve stage in the DMAIC cycle is the most important part as it is at this stage that the changes to normal practices will be decided and implemented. The define, measure and analyse stages have only set out the problem, established a measurement of it and identified where the possible failures are. Reviewing the findings in the analyse stage for the process the initial improvements made should be to standardise the working practises of the operators and give them training in the areas identified as weaknesses. This platform of standard working can then be used as a basis for the improvements to follow in the second and third DMAIC cycles[27].

Using the 5S principles as a basis for standardisation a three-day activity was arranged allowing all of the operators to come off their shift pattern to work together along with a small team of personnel from maintenance and management. During the three days the team set about going through the 5S process and during that time, reference was made to the main failure modes identified in the OEE and subsequent Pareto analysis. Also during the 3 day activity, the team identified and implemented other improvement opportunities. The maintenance team members completed the engineering modifications as well as carrying out planned maintenance on the plant. There had been no planned maintenance on the line for 12 months due to production planning not releasing the machine because of poor production output leading to supply constraints.

On the first day the team sorted out all of the tools, equipment and paperwork currently being used. Instead of red tagging each item the team were able to make the decision of what was needed and what was not needed immediately as all the relevant personnel were participating in the activity. Once all of the tools had been sorted and new locations found, the plant was given a full clean-up and oil leaks were traced and minor faults repaired. The remaining tools were then allocated storage places and tool and storage locations were marked up to identify what went where.

During the second day the team set about stripping, cleaning and reassembling the extruding die. The objective here was to establish and document a standard procedure agreed by and used by all the operators in the future. As well as the new procedure for stripping and cleaning the die the machine operators requested a small notice be manufactured to show the torque settings for each element of the die during reassembly. The notice was manufactured and put up adjacent to where the setters would be able to see it whilst they would be working on the die.

[27] This links directly to the preceding Chapter where 5S was introduced as a requirement to base process improvements on. In this example the process has been found to have no standard working and therefore the first stage in the improvement process must be to establish standardised working through 5S.

On the third day the team moved on to the corrugator to standardise the setting of this unit of plant. The main finding during the training activity was the correct positioning of control sensors on the corrugator manually located in place with no vernier scale or markings for alignment. The operators felt that this could be causing some of the problems with quality failures and a simple setting system was required. Imai (1997) suggests a methodology for fail proofing and calls it *poke-yoke*, roughly translated into English as fool proofing. A good example of a poke-yoke device is a British Standard domestic electrical plug. The three pinned plug will only fit into the socket one way and it is impossible to fit it incorrectly. Using this approach the improvement team came up with a setting device to show exactly where each of the sensors should be located for each of the different settings on the corrugator.

The final part of the third day was spent setting up trouble-shooting matrixes to assist the operators in the future when problems occur. The matrixes were designed to direct the operator to what process variable was causing the failure mode and effect on the pipe. For ease of use, the troubleshooting matrix was designed using a colour coding system and priority numbers to highlight the process variables to adjust first. The operator is first guided to the variable marked in red rated as 6 which are the dependant factors. If this does not work then the operator is guided to the other variables that may help adjust the process into specification. These are highlighted in blue with a rating of 3 meaning, "*has some relationship to*". The other variables rate as zero and are of no significance to the problem and any adjustments to these would not correct the problem and may cause other problems.

5.4.6 Control

The control methods suggested by George (2002) and Pande *et al.* (2000) are inherent within the improvement made on the process. The actual improvements made have been to control the actions of the operators putting in place systems and tools to ensure that the process is set and run the same way each time. The use of setting procedures, poke yoke devices, trouble shooting matrixes, standard tool storage and information notices are themselves control tools. During the 3 day activity a process operator's manual was set-up which contained all of the new standard working documents and troubleshooting matrixes. The manual was placed in a purpose built lectern at the machine control panel for ease of access and use.

5.4.7 OEE & DMAIC Case Study Findings

After the improvement activity was completed, data was captured for a further six-week period. The post improvement results show the OEE has nearly doubled to 62% from an original 34% with the results of the second part of the data capture presented by the Author in Figure 23. This improvement prompted the production line to be planned in for a one month shutdown due to predicted high stock levels, resulting in a saving of over £15k in labour rates as the resources were used on other processes. Also, the regrind generation dramatically reduced from a previous average of 13% to 5% equating to a saving in material costs of £210k including the product re-processing costs.

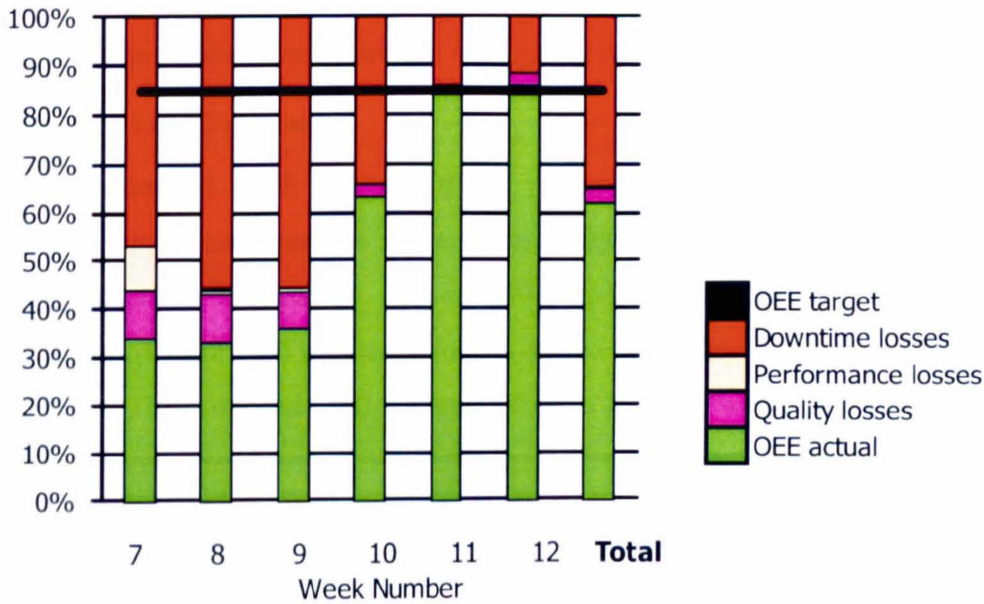

Figure 23: OEE Results after Improvement

5.5 Developing OEE as an Indicator of Lean Six-sigma Capability

5.5.1 Introduction

Although the OEE measure is seen as a useful and powerful KPI the system is not without criticisms warranting further investigation. The taxonomic and captious review of the lean, TPM and OEE literature has identified the original framework for calculating OEE (Nakajima, 1988; 1989) is now seen as anachronistic to the needs of businesses who require a more holistic indicator of plant and process effectiveness (Ljungberg, 1998; Jonsson and Lesshammar, 1999; Jeong and Phillips, 2001; Parida and Kumar, 2006; Muchiri and Pintelon, 2008).

Developing the OEE measurement framework further, this section of the thesis discusses how OEE can be developed further overcoming extant criticisms without moving away from the original calculation framework presented by Nakajima (1988), as have other OEE developers (Raouf, 1994; Jonsson and Lesshammar, 1999; Muchiri and Pintelon, 2008). The proposed framework introduces an indication of six-sigma process capability using the extant data from the quality section of the OEE calculation and an indication of asset management effectiveness through indicators of asset reliability, availability & maintainability (RAM) calculated using the extant data from the availability element of the OEE calculation. The benefits of these additions are realised through the internal and/or external benchmarking of performance levels against a given requirement driving continuous improvement based around objective data (Dal *et al.*, 2000).

5.5.2 Proposed OEE Framework

An extended OEE framework is proposed that incorporates six-sigma thinking and asset management strategy performance indicators. In Figure 24 the Author presents a breakdown of the OEE calculation structure showing the incorporation of additional measures for six-sigma capability and asset management effectiveness. The proposed OEE is viewed from a lean and waste perspective.

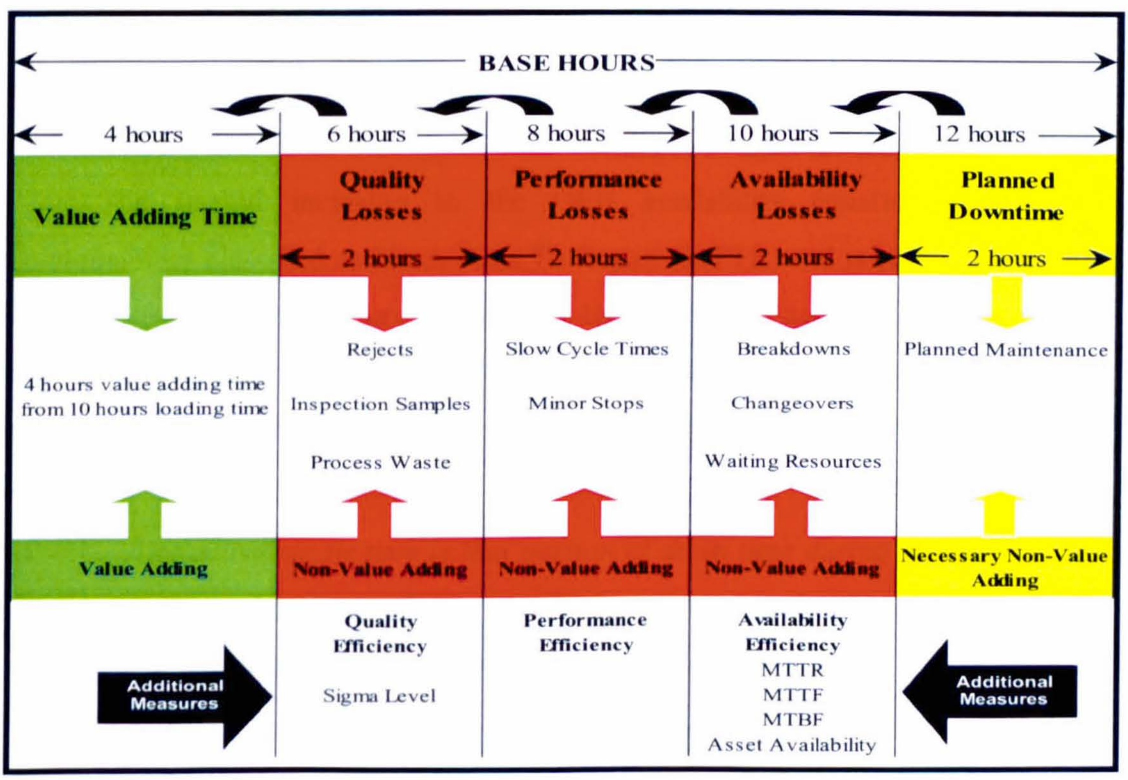

Figure 24: Extended OEE Table Example

Relating directly to the categorisations of value introduced by Womack & Jones (1996b), Figure 24 also categorises the value adding (VA), non-value adding (NVA) and necessary but non-value adding (NNVA) elements to an OEE calculation: -

- The final OEE measure is the value adding element of the base hours available,
- The availability, performance and quality losses are all categorised as non-value adding, pure waste.
- The planned downtime is categorised as necessary but non-value adding.

The proposed OEE framework availability element is enhanced to include three additional measures of asset management effectiveness. The first new indicator focuses on asset reliability classified as Mean Time To Failure (MTTF) and is based on the actual production hours (total operating time minus any down time) divided by the number of asset failures during that time. Davidson & Hunsley (1994) define reliability as -

> *'The probability that a component, device, or system will perform its prescribed duty without failure for a given time when operated correctly in a specified environment.'*

Kelly (1997; 2001) suggests reliability as an indicator of asset management effectiveness can be shown as:-

$$MTTF = \frac{\text{Actual production hours}}{\text{Number of asset failures}} \qquad (5)$$

The second inclusion to the OEE availability equation focuses on maintainability classified as Mean Time To Repair (MTTR) and is based on the total downtime (due to asset failure) divided by the number of asset failures during the total operating time. Thompson (1999) argues maintainability relates to the time required to return a repairable piece of plant to its previous state of condition. Sheriff (2003) defines maintainability as: -

> *'.....The active repair time is that portion of down time during which the system is worked on to effect a repair. Repair time includes preparation time, diagnostic time, correction time and final checkout time.'*

Thompson (1999) suggests maintainability as an indicator of asset management effectiveness can be shown as:-

$$\text{MTTR} = \frac{\text{Total downtime}}{\text{Number of asset failures}} \quad (6)$$

The third inclusion to the OEE availability equation focuses on the total time between failures classified as Mean Time Between Failures (MTBF) and is based on the MTTF plus the MTTR. Unlike MTTF -which is a pure indicator of reliability- MTBF includes the repair time to give an overall indicator of asset management effectiveness. MTBF as an indicator of asset management effectiveness can be shown as:-

$$\text{MTBF} = \text{MTTF} + \text{MTTR} \quad (7)$$

Developing the quality element of the OEE equation, George *et al.* (2004) suggest defects per million opportunities (DPMO) as a measure of process capability and can be shown as: -

$$\text{DPMO} = (\text{Good Production} / \text{Total Production}) \times 1000\,000 \quad (8)$$

$$\text{Sigma Level} = \text{DPMO value in Table 12} \quad (9)$$

Sigma Level	DPMO	Sigma Level	DPMO	Sigma Level	DPMO
1.5	500 000	4.01	6 000	5.31	70
1.75	400 000	4.08	5 000	5.35	60
2.02	300 000	4.15	4 000	5.39	50
2.34	200 000	4.25	3 000	5.44	40
2.78	100 000	4.38	2 000	5.51	30
2.84	90 000	4.59	1 000	5.61	20
2.91	80 000	4.62	900	5.77	10
2.98	70 000	4.66	800	5.78	9
3.05	60 000	4.69	700	5.82	8
3.14	50 000	4.74	600	5.84	7
3.25	40 000	4.79	500	5.88	6
3.38	30 000	4.85	400	5.91	5
3.55	20 000	4.93	300	5.97	4
3.83	10 000	5.04	200	6	3.4
3.87	9 000	5.22	100	6.12	2
3.91	8 000	5.25	90	6.27	1
3.96	7 000	5.27	80		

Table 12: Sigma Level Reference Table

Pyzdek (2003) argues for multiple process steps the rolled throughput yield (RTY) DPMO should be calculated as follows: -

$$\text{RTY} = ((1 - \text{DPMO}_{1} / 1000\,000)) \times ((1 - (\text{DPMO}_{n} / 1000\,000)) \quad (10)$$

Operationalising the proposed OEE framework the following calculation guide details the steps to evaluating the availability (including MTTF, MTTR & MTBF), performance and quality (including six-sigma) elements within the new framework. The equations presented are adaptations of equations 1-6 transposed (where necessary) into the format required to incorporate them into the enhanced OEE calculation framework.

OEE: Loading Time

The loading time is based around the time available deducting any planned downtime such as planned maintenance. As previously stated, this time is classified as NNVA and is a waste that can potentially be eliminated or reduced. A useful comparison would also be the ratio between planned maintenance time and unplanned maintenance time.

Loading Time = standard minutes available - planned downtime (11)

OEE: Availability

The availability efficiency is based around incorporating asset management effectiveness measures: MTTR, MTTF & MTBF in addition to understanding the usual process availability losses such as set-up and adjustment times. All availability inefficiencies are classified as NVA and seen as pure waste which must be eliminated to improve the OEE.

Total Lost Time	=	Total process downtime + total asset repair time	(12)
Total Repair Time	=	Total asset repair time	(13)
Actual Run Time	=	Loading time – total lost time	(14)
MTTF	=	Actual run time / no. of repairable asset failures	(15)
MTTR	=	Total repair time /no. of repairable asset failures	(16)
MTBF	=	MTTF + MTTR	(17)
Availability (%)	=	(Actual run time / loading time) x 100	(18)

OEE: Performance

The performance efficiency is exactly the same as was originally defined by Nakajima (Nakajima, 1988) and is based on the actual throughput compared to the potential throughput (from the actual runtime). As with the availability losses, all performance inefficiencies are classified as NVA and seen as pure waste which must be eliminated to improve the OEE.

Performance (%) = Throughput / (cycle time / actual runtime) x 100 (19)

OEE: Quality

The quality efficiency is based around incorporating an indication of six-sigma process capability through the DPMO measure in addition to understanding the usual process quality losses such as setting pieces, attribute inspection failures and dimensional inspection failures. As with the availability and performance inefficiencies, all quality inefficiencies are classified as NVA and seen as pure waste which must be eliminated to improve the OEE.

DPMO = (Total bad production / total good production) x 1000 000 (20)

Quality (%) = (Total good production – total bad production) / (total good production) x 100 (21)

Overall Equipment Effectiveness

The final OEE gives an indication of the total value adding % to the time available taking into account the availability, performance and quality inefficiencies:-

OEE% = Availability % x Performance % x Quality % (22)

Neely *et al.* (1995) suggest all performance measurement systems consist of a number of individual performance measures. Using the measurement system framework proposed by Neely *et al.* (1995), Figure 25 summarises the proposed OEE measurement framework as presented by the Author showing the individual performance measurement system elements and their relationship to the overall equipment effectiveness performance measure. For clarity, the gross process throughput shown in the Performance element of Figure 25 indicates the total production yield including any non-conforming parts, whereas the net process throughput shown in the Quality element represents the usable production yield differentiating by removing the non-conforming parts.

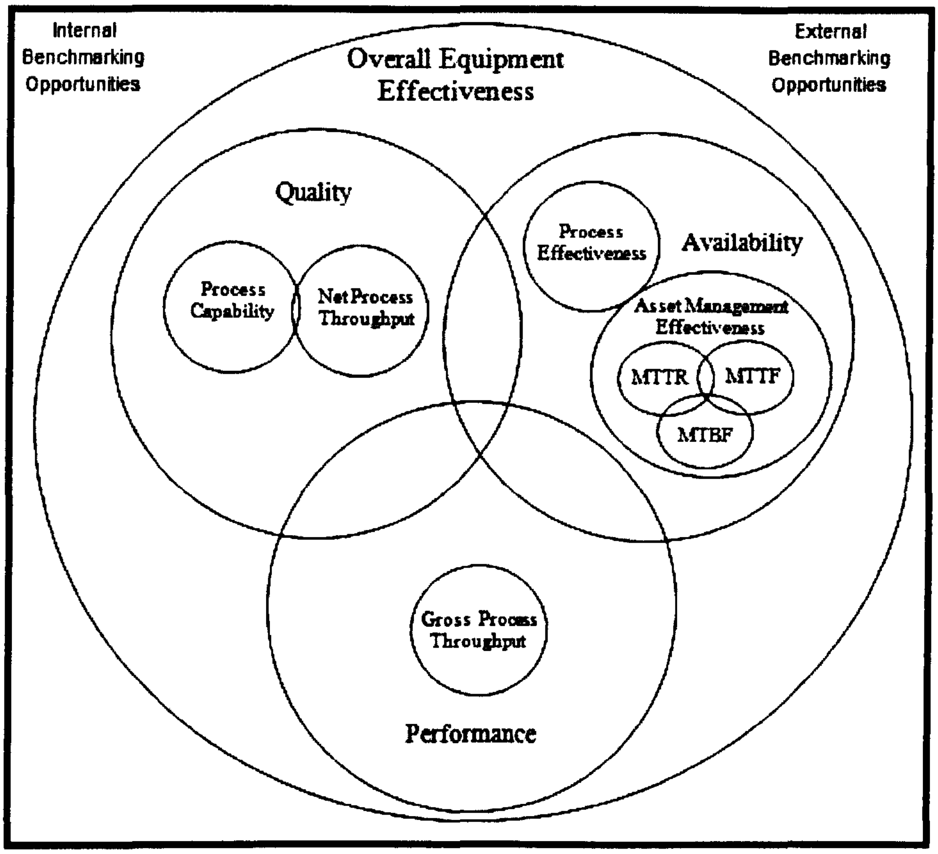

Figure 25: OEE as a Performance Measurement System

5.6 OEE as a Measure of Lean Six-sigma Capability Case Study Example

Company Z operates within the fast moving consumer goods (FMCG) market sector of the UK manufacturing industry specialising in the manufacture and assembly of aerosol valve assemblies and aerosol actuators. The measurement framework introduced in this paper was developed in parallel to the installation of a new injection moulding and assembly process for manufacturing aerosol actuators. Developing the OEE framework through the installation, commissioning, process capability trials and production ramp-up stages on new machinery provided an opportunity to fully appreciate the relationship between, asset management effectiveness (in this case focused on the reliability of the asset during the infant mortality lifecycle and useful life phases (Davidson and Hunsley, 1994)); operational capability (measuring predictable operational activities such as line changeovers), process performance (measuring against an expected throughput) and process capability (measuring the output quality and sigma level).

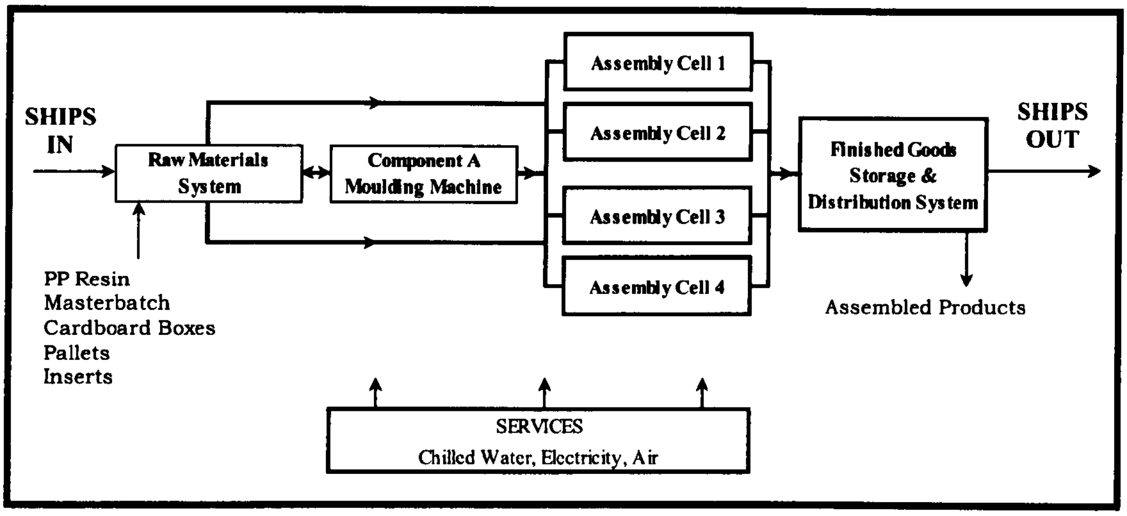

Figure 26: Process Flow Value Stream

The first stage in developing the OEE measurement framework is to understand the scope of the process to be measured and to agree what is value adding and not value adding in the eyes of the customer. To facilitate the scope setting two lean six-sigma tools can be utilised. The first tool is used to identify and understand the value stream and natural flow of material through the manufacturing process, regardless of plant layout. The process flow diagram in Figure 26 shows the main process steps from raw material being shipped in through to the finished goods being shipped out as presented by the Author. The flow diagram is also used to indicate where the process has multiple parallel operations and singular series operations.

For this case study the Component A moulding machine is shown as a singular process feeding into four assembly cells operating in parallel. This indicates the Component A injection moulding machine is a critical piece of plant and if not available then could stop the downstream assembly processes. To prevent this happening, a buffer of stock is used with components from the moulding machine being stored in a warehouse before issuing to the assembly processes. From a lean perspective this is pure waste and leads to increased inventory levels and extra transportation. The ideal value stream would be for Component A to be fed directly from the injection moulding machine into the assembly cells.

With a focus on the critical injection moulding machine the Supplier, Input, Process, Output, Customer (SIPOC) diagram tool can be used to set the scope of the OEE measurement and identify the key inputs and customers. Figure 27 represents the SIPOC diagram for Company Z setting the scope of the OEE measurement framework for the injection moulding machine manufacturing Component A as presented by the Author.

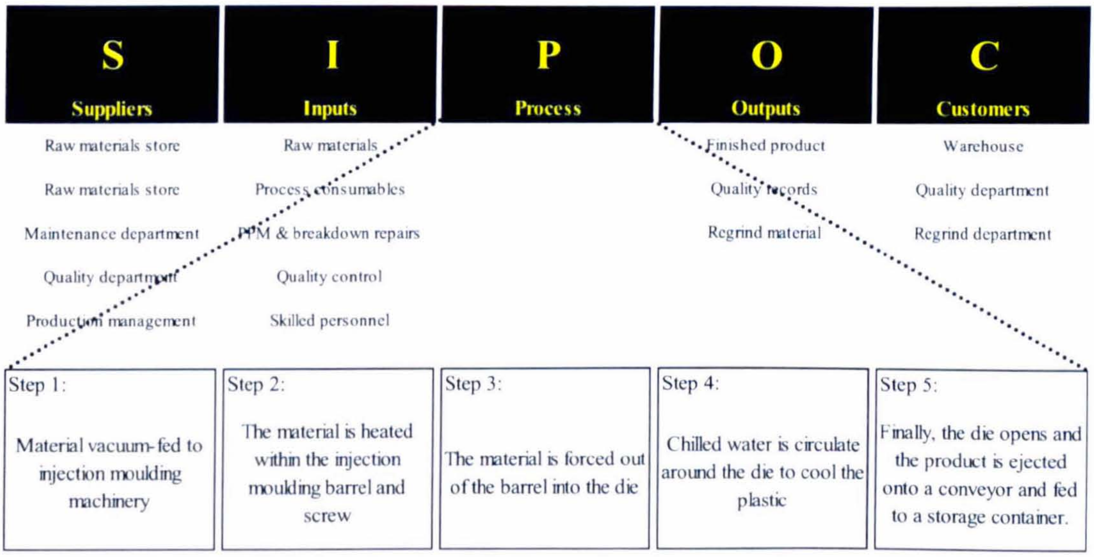

Figure 27: SIPOC of Injection Moulding Process

From the SIPOC diagram the scope of the process to measure is defined in the steps 1-5 and the value adding contribution is defined by the customer outputs. Perhaps more important is the definition of what is not included in the scope preventing confusion and providing focus on the defined process.

Once the scope of the OEE process to be measured has been confirmed and the value adding contribution defined the shop floor data capture system must be developed and failure mode categories identified in relation to the OEE categories. For the injection moulding process a manual data capture system was employed with the machine operators and setters agreeing on the potential failure modes and format of the data capture sheet. This data was then transferred directly onto an OEE calculation spreadsheet and the raw data analysed.

Table 13 introduces the extended OEE calculation table using data collected from the injection moulding process to show how the additional indicators of six-sigma and asset management effectiveness are incorporated into the original OEE framework as presented by the Author. Table 13 also shows how the enhanced OEE framework can be used to indicate the OEE of a process for an individual shift, day, week or month. This cumulative approach can also be applied to groups of machinery (such as all the injection moulding machines in Company Z of this case study) facilitating the benchmarking between individual pieces of plant or different businesses over any required period of time.

CATEGORY	CALCULATION	DESCRIPTION	SHIFT *n*	DAY *n*	WEEK *n*	MONTH *n*	CUSUM
LOADING TIME	A	Standard Minutes Available	720	1440	7200	28800	38160
	B	Planned Downtime	120	240	1000	4500	5860
	C = A - B	Loading Time	600	1200	6200	24300	32300
AVAILABILITY		Line Changeover	60	60	60	60	240
		Adjust Process	20	20	20	20	80
		Waiting Material	0	0	0	0	0
		Waiting Operator	0	0	0	0	0
	D	Asset Repair Time	120	240	2000	8000	10360
	E	Total Lost Time	200	320	2080	8080	10680
	F = C - E	Actual Runtime	400	880	4120	16220	21620
	G	Number of Asset Failures	4	8	20	100	132
	H = F / G	MTTF	100	110	206	162	164
	I = D / G	MTTR	30	30	100	80	78
	J = H + I	MTBF	130	140	306	242	242
	K = (F / C) x 100	**Availability Efficiency**	**66.67%**	**73.33%**	**66.45%**	**66.75%**	**66.93%**
PERFORMANCE	L	Total Parts Made	1500	3000	15000	60000	79500
	M	Cycle Time (Minutes)	0.2	0.2	0.2	0.2	0.2
	N = L / (M / F) x 100	**Performance Efficiency**	**75.00%**	**68.18%**	**72.82%**	**73.98%**	**73.54%**
QUALITY		Out of tolerance parts	20	40	200	1000	1260
		Setting Parts	5	10	30	120	165
		Attribute Failures	30	60	120	500	710
	O	Total Bad Parts Made	55	110	350	1620	2135
	P = (O / L) x 1000,000	DPMO	36667	36667	23333	27000	26855
	R= ((L - O) / L) x 100	**Quality Efficiency**	**96.33%**	**96.33%**	**97.67%**	**97.30%**	**97.31%**
OEE	**= K x N x R**	**Overall Equipment Effectiveness**	**48.17%**	**48.17%**	**47.26%**	**48.05%**	**47.90%**

Table 13: Extended OEE Calculation Table

Through the installation to production ramp up phases, the OEE data was used as an overall measure of process potential and inefficiencies were identified through the individual calculation elements and analysed to identify the root causes and subsequent improvement plans. Using this 'Define/Do', 'Measure', 'Analyse', 'Improve/Control' approach -using the data collected from the injection moulding process- a significant improvement was made taking the process potential from an initial OEE of 40%, up to the required production OEE level of 85% within a 3 month period. The 45% improvement in OEE was justified by the Managing Director and equipment supplier when they approved the equipment for full production use and the final capital payment was paid to the equipment supplier. Interestingly, one of the key areas of improvement made was in the local services supplied centrally by Company Z. Compressed air and chilled waters supplies to the equipment were found to be inadequate for the new process and had to be upgraded to match the requirements. As a result of the OEE improvement and confidence in the injection moulding process the components were no longer sent to the warehouse and were fed directly onto the assembly process with minimal inventory held on the shop floor.

5.6.1 Key Lessons Learned & Management Implications

Reviewing the management implications for OEE and TPM implementation, a critical element to the success of OEE –like all performance measurement systems (Neely *et al.*, 1995)- is the reliance on a valid and reliable data collection system (Muchiri and Pintelon, 2008). Dal *et al.* (2000) argue the credibility of the OEE measure is dependent on the accuracy of performance data and propose the investment in time is important to improve sources of data collection. Jeong & Phillips (2001) suggest the accuracy of the OEE calculation is determined by the quality of data collected and recommend one approach to achieving this is the use of a computerised data collection system. Ljungberg (1998) criticises the sole use of computerised data collection systems for OEE calculation arguing the systems are difficult to use by operators, engineers and supervisors and proposed the use of a combined computerised/operator data collection system where computerised models support local process knowledge and plant operators are involved in setting up the data collection. Therefore key lessons learned from the case study investigation focus around the data collection and subsequent OEE validity. Involving the operations team in the development of the data collection system and sharing the process of analysis greatly helped in collecting the data. However, the management implications of this approach meant initially the operations team were taken off-line to develop the data capture method and this required an investment in time. Further time was also required to manually record the OEE performance which over time was greatly reduced as their familiarity with the data capture and analysis improved. This data collection and analysis time could be eliminated completely through investment in an automated data capture system as suggested by Ljungberg (1998). Involving the process operations teams in the development process also gave ownership of the measure; improve process, encouraging the measurement process sustainability once the researcher intervention was removed.

5.7 Discussion

5.7.1 OEE & DMAIC

R2. Can the lean measure of overall equipment effectiveness (OEE) be used within a six-sigma DMAIC improvement process?

This section of the thesis has introduced the TPM measure of Overall Equipment Efficiency/Effectiveness as a useful Key Performance Indicator and data collection tool to be used in conjunction with the DMAIC six-sigma methodology for improving a single process. In particular the OEE measure has been shown to provide objective data based on past failure modes of plant; eliminating the need to use more subjective methods such as FMEA to identify where improvements can be made. The OEE also gives a measure of the combined effects of plant availability, performance and quality which complements the six-sigma measure of process capability.

From a six-sigma methodology perspective, this approach has introduced the concept of a triangulated project approach using both objective, quantitative methods for data analysis and problem solving as well as using subjective, qualitative methods for dealing with the personnel elements of a six-sigma project. The foundation of this concept originates from the requirement to gain buy-in from shop floor personnel; one of the critical success factors to a six-sigma project.

Key findings from this investigation include: -

- The six-sigma DMAIC cycle has been proven as a useful methodology for improving the OEE of an individual piece of plant.
- 5S can be used in conjunction with the six-sigma DMAIC process to standardise both the soft (procedures, skills and work systems) and the hard (tool availability, tool storage, tool identification) elements of a manufacturing operation.
- By standardising the process the OEE 'best-of-the-best'[28] may not improve but the worst-of-the-worst will get better. Also, the performance element of the OEE equation will always be 100% if the process is running to standard.

[28] Best of the best (BOB) is an indicator of proven process potential calculated by multiplying the highest availability, performance and quality efficiencies achieved. Similarly, the 'worst of the worst' (WOW) can be calculated from the lowest availability, performance and quality efficiencies.

- Pareto analysis is a useful tool for homing in on the areas to be improved and can be directly related to the witnessed OEE losses.

5.7.2 OEE as an Indicator of Lean Six-Sigma Capability

R3. Can the measure of OEE be expanded to incorporate asset management indicators and a level of six-sigma capability giving a holistic indicator of lean six-sigma capability?

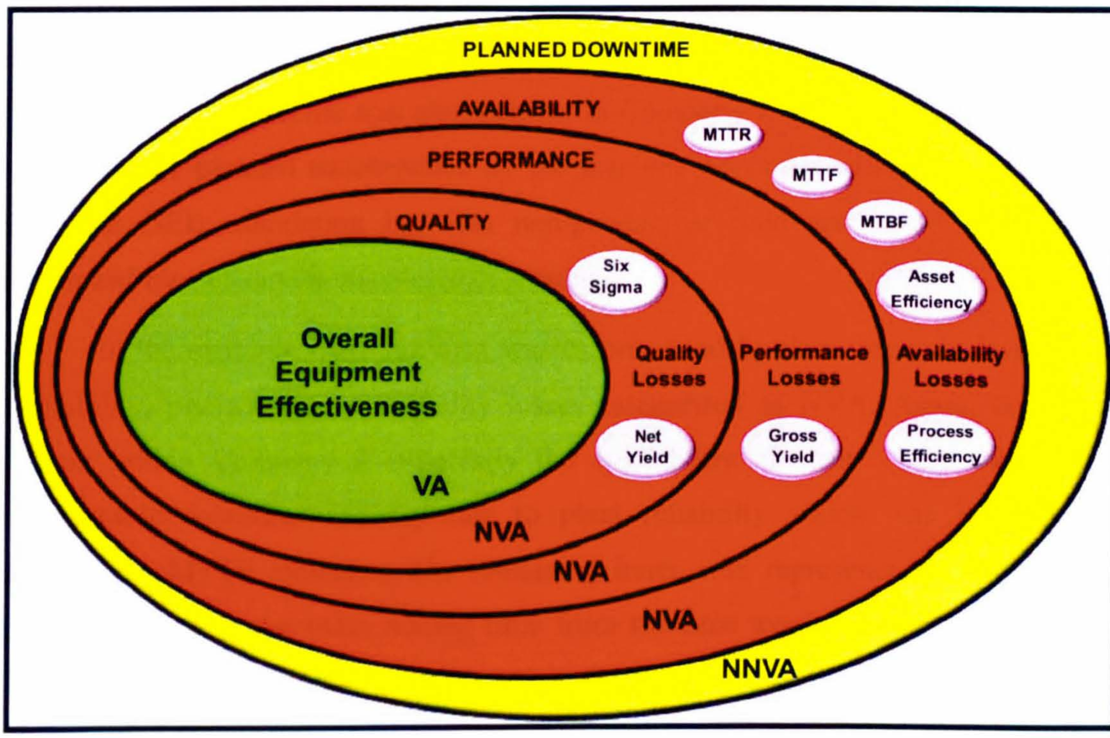

Figure 28: OEE Value Analysis System Map[29]

Jonsson and Lesshammar (1999) argue OEE simplifies the total measurement system but on its own is not a measure of overall manufacturing performance (OMP) and therefore has to be complemented by other measures. Developing the OEE measurement framework to be a more holistic measure an enhanced OEE framework has been introduced based around incorporating an understanding of asset management effectiveness –measured against MTTF, MTTR & MTBF- into the availability element of the OEE calculation and an understanding of process

Understanding what happened when the WOW was achieved could provide useful information to improve the OEE. Similarly, understanding what happened/did not happen when the BOB was achieved could be fed back into the process to drive improvements.

[29] This is no different to peeling layers off a very big onion where the individual layers removed unnecessarily when peeling are lost and the remaining usable element of the onion is much smaller than it could have potentially been.

capability –measured against six-sigma levels- into the quality element of the OEE framework.

Figure 28 summarises the key elements to the enhanced OEE framework as presented by the Author indicating the VA, NVA & NNVA categorisations within a system map of the OEE calculation. The outer edge of the system map represents potential time available and if there was no waste in the system (NVA and/or NNVA) the inner space would represent the OEE value. However, in the example there is a time allowance for planned maintenance represented by a single layer and classified as NNVA. This was also evident in Company Z where there was a daily allowance for planned maintenance by the machine operators which was excluded from the OEE calculation but was non-productive time and could have been eliminated by a change in maintenance strategy.

In the example there are also wastes presented by three separate layers for availability, performance and quality losses categorised as NVA. Again, this was evident within Company Z especially the availability element where there was considerable downtime initially due to plant reliability which was highlighted through the MTTF indicator. The remaining inner core represents the final OEE value representing the value adding time from the time available (the outer edge). The NVA & NNVA wastes represented in Figure 28 were all evident in the case study carried out at Company Z.

Viewing OEE from a lean & waste perspective takes the purpose of measuring performance back to the original objective of lean production, the elimination of waste in all of its forms (Ohno, 1988). Jeong & Phillips (2001) argue OEE should be defined as the valuable production time from the total calendar time available including all NNVA and NVA wastes into the OEE calculation. Therefore, developments to the OEE framework must also focus on understanding what is value-adding in the eyes of the customer before the identification and subsequent elimination of any NNVA and NVA wastes.

The successful improvement to any process based OEE is the dependence on first understanding the characteristics of NVA & NNVA losses as this will increase the chances of eliminating waste (Jeong and Phillips, 2001). Focusing on the availability element of the OEE calculation, Dal *et al.* (2000) have found the availability element is typically made up of maintenance engineering losses and production related losses. Historically though, OEE has focused on the production losses related to availability typically ignoring the maintenance engineering losses which impact the process (Muchiri and Pintelon, 2008) and also moves away from measuring total productive maintenance as originally defined by Nakajima (1988; 1989). Muchiri & Pintelon (2008) propose including MTBF and MTTR as measures of maintenance effectiveness in relation to availability in the OEE calculation.

Jeong & Phillips (2001) propose using reliability and maintainability indicators to support their OEE framework which incorporates planned maintenance into the availability element arguing this NNVA time must be captured for capital-intensive industries. Ahuja & Khamba (2008) argue OEE offers a starting point for relating maintenance measurement to corporate strategy giving a quantitative measure of the reliability of the system. The usefulness of the additional measures of asset efficiency with a value-adding focus was proven within the case study at Company Z where the availability was improved from 40% to 85% during the 3 month study of the injection moulding machine manufacturing component A.

Madu (1999) suggests, quality and reliability are synonymous and a system cannot be reliable if it does not have high quality and a system cannot be of high quality if it is not reliable. Adding asset management effectiveness and six-sigma measures to OEE puts a focus on these two key contributors to the overall equipment effectiveness measure and provides a more holistic indicator of business effectiveness. Complementing the proposed asset management effectiveness measures, an indicator of six-sigma process capability was introduced as a necessary indicator to understanding process quality.

The focus on quality within the OEE calculation can be overlooked when figures of 99% are achieved as per Nakajima's (1988) ideal value for quality. Goh (2010) agrees, arguing when fully understanding the consequences from a six sigma and statistical perspective, *"99% good, is not good enough"*. Transferring a quality level of 99% to six-sigma capability gives a sigma level of only 3.8 sigma and an expected quality yield of over 10,000 defects per million opportunities (DPMO) (George, 2002). This shows the simplicity of the quality element of the OEE calculation in relation to the six-sigma objective where the target is a quality yield of 99.9996% with a reject rate of 3.4 parts per million opportunities (Pande *et al.*, 2000).

The OEE availability and quality efficiency calculations as proposed by Nakajima (1988) are therefore too simplistic for delivering quantifiable and data based improvements to the resource bundles providing a service to a business. To improve the OEE a more in-depth understanding of the data informing these elements must be made. For example, developing the availability calculation the data must inform whether there is a problem with the asset efficiency and/or operation efficiency before drilling down further to understand where improvements must be made.

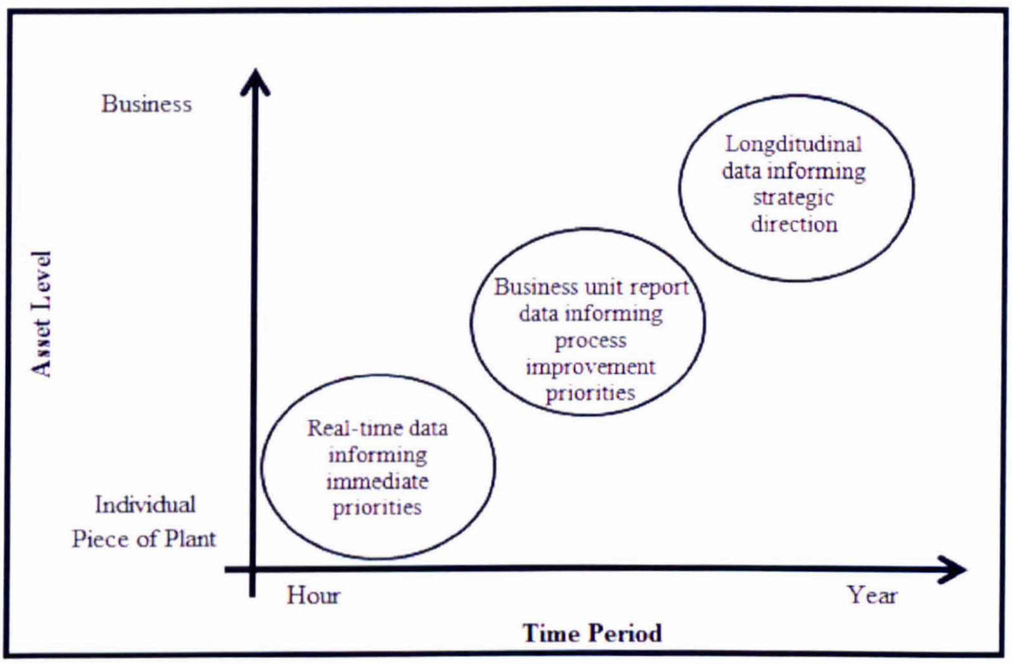

Figure 29: OEE Data Usage Opportunities

The enhancements to the OEE framework have been developed without detracting from the original OEE calculation framework allowing for the benchmarking at individual asset or business levels over any required period of time. In Figure 29 the Author shows how the enhanced OEE data can also be used to inform business priorities with respect to immediate priorities, process improvement priorities and strategic direction. For example, the asset management effectiveness measures can help inform the business level asset replacement plans facilitating strategic direction based on objective and holistic measures of overall equipment effectiveness.

Also, as a strategic level measure OEE is important to inform opportunities for competitive advantage by identifying business core competencies (Prahalad and Hamel, 1990) and capabilities (Stalk *et al.*, 1992) which can be used to differentiate the business from competitors, a key objective to achieving sustainable competitive advantage (Barney, 1991; Peteraf, 1993).

Contributing to the development of a lean six-sigma conceptual framework - where there is currently a paucity of published material (Pepper and Spedding, 2010)- the enhanced OEE framework is introduced as an indicator of lean six-sigma capability.

5.8 Conclusion

This section of the thesis has introduced two very useful developments to the lean and six-sigma conceptual frameworks demonstrated through case study examples. The use of OEE as a measure in the DMAIC process has provided a useful framework for improving equipment effectiveness in a structured approach which can easily be replicated. Complementing this new approach is the development of OEE into a more holistic measure of lean six-sigma capability.

Linked to the OEE DMAIC case study presented in this Chapter, the next Chapter will introduce the concept of a Lean Resource Mapping Framework developed to understand how resources can be better deployed to improve OEE.

Chapter 6: Developing a Lean Resource Mapping Framework

6.1 Introduction

Linking back to the preceding Chapters, this section of the thesis will build upon the 5S and OEE concepts adding the concept of a lean resource mapping framework in the development of a value improvement model for repetitive processes. This Chapter is based upon three published papers and one paper currently under review for publication.

Paper one was presented at and published in the conference proceedings of the 2nd International Six-sigma Conference held at Glasgow University Business School in June 2006 (Gibbons, 2006a) and makes a link between OEE and the Resource Based View of the Firm (RBV). The second paper was presented at and published in the conference proceedings for the First European Research Conference on Continuous Improvement & Lean Six-sigma held at Strathclyde University in March 2008 (Gibbons, 2008b) and shows the development of a Lean Resource Mapping Framework. This paper was developed further and published in the International Journal of Six-sigma and Competitive Advantage in 2008 (Gibbons, 2008b). The final paper has been submitted for publication in the International Journal of Lean Six-sigma and introduces the concept of an eighth waste to complement the seven wastes of lean (Gibbons and Burgess, 2011).

To-date, lean principles have focused on the elimination of waste (Ohno, 1988) taking a one dimensional view of the linear processes relating to customer driven product value streams (Womack and Jones, 1996b; Hines and Rich, 1997; Rother and Shook, 1998; Hines *et al.*, 2000; Jones and Womack, 2003); deliberately ignoring any connectivity with other products and processes, people and plant. Typically Value Stream Mapping (VSM) (Rother and Shook, 1998; Jones and Womack, 2003) has been used as a static analysis tool to operationalise Ohno's (1988) taxonomy and quantify the 7 wastes of lean. The research argument and justification suggests a more holistic approach, taking into account possible resource connectivity(s), that will deliver lean resources that are homogenous (across value streams) rather than heterogeneous (between value streams); providing overall business efficiency and effectiveness rather than disparate value stream efficiencies.

6.2 Strategic View

Identifying and understanding sources of sustained competitive advantage is a key objective in strategy based literature (Rumelt, 1984; Porter, 1985). For example, Barney (1991) presents a useful framework (*cf.* Figure 30) for understanding how to achieve sustained competitive advantage. The framework argues exploitation of internal strengths must be matched to external environmental opportunities, whilst managing external threats and internal weaknesses.

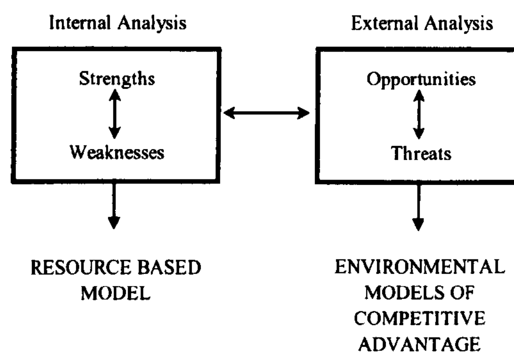

Figure 30: Achieving Sustained Competitive Advantage (Barney, 1991)

Barney's (1991) model also introduces two of the dominant schools of thought replete in strategy literature. The external analysis perspective is the more traditional and represents a model of the industrial organisation (IO) taking a market based perspective looking from the outside-in to identify opportunities for achieving competitive advantage (De Toni and Tonchia, 2003). The roots of the IO approach can be found in the work of Bain (1959), Ansoff (1968) and Andrews (1971) with further developments made by Porter (1980; 1985).

In contrast, the internal analysis perspective takes a Resource-Based View (RBV) of a firm, looking from the inside-out, identifying opportunities for competitive advantage (De Toni and Tonchia, 2003) realised through different amalgams of productive and strategic resources (Wilk and Fensterseifer, 2003). The seminal work introducing the perspective of a RBV was made by Wernerfelt (1984) although Foss (1997) argues the ideas informing a RBV can be traced back to earlier work (Selznick, 1957; Penrose, 1959; Chandler, 1962; Andrews, 1971; Richardson, 1972; Demsetz, 1973; Nelson and Winter, 1982).

Of the two strategy perspectives introduced, the RBV -with its internal environment focus of resources- can be linked to process improvement and is worthy of further investigation.

6.2.1 A Resource-Based View

Although Wernerfelt (1984) suggests resources and products are two sides of the same coin the argument is made that a RBV offers a useful perspective of strategic options specifying internal resources to find the optimal product-market activities. Operationalising the theory, Wernerfelt (1984) introduces a resource-product matrix as a simple, but powerful tool, indicating the importance between resources and products, and vice versa (*cf.* Figure 31).

RESOURCE / MARKET	I	II	III	IV	V
A					
B					
C					
D					
E					

Figure 31: Resource-Product Matrix (Wernerfelt, 1984)

Wernerfelt (1984) suggests resources are anything that could be thought of as a strength or weakness of a given firm, defining resources as '*tangible and intangible assets which are tied semi-permanently to the firm*'. Antecedent work by Penrose (1959) argued resources bundled together, render a service as an input to a production process and it is these bundles of resources -providing potential services- that are the source of uniqueness in each individual firm. Penrose (1959) also suggested unused productive services are a '*waste*'[30], that they are potentially free and therefore, if used profitably, can provide competitive advantage.

Developing the RBV further, Barney (1991) identifies sources of sustainable competitive advantage linked to firm resources. Building on the assumptions that resources are heterogeneous and stable over time, Barney (1991) argues there are four potential indicators to a firm achieving sustainable competitive advantage:

[30] As has already been discussed in detail, the concept of waste elimination is a key objective of lean thinking.

valuable resources, rare resources, imperfectly imitable resources and *substitutability.* Complementing Barney's (1991) work, Peteraf (1993) introduces an economic based model of competitive advantage, arguing four conditions must be met to enjoy above-normal returns *–heterogeneity, ex-post limits to competition, imperfect mobility* and *ex ante limits to competition* (*cf,* Figure 32).

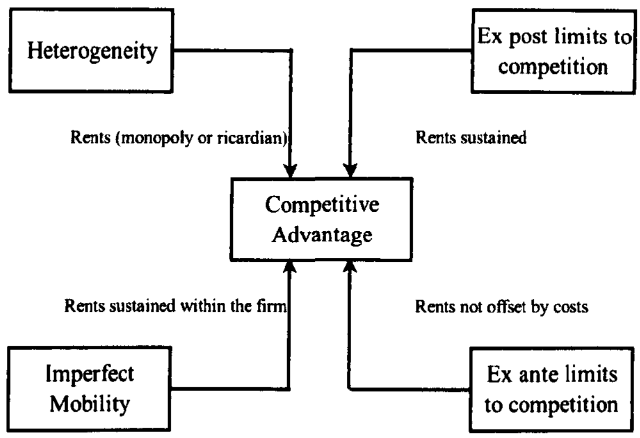

Figure 32: Four Cornerstones of Competitive Advantage (Peteraf, 1993)

Introducing the concept of *'core competences'* to the RBV literature, Prahalad & Hamel (1990) argue the future of corporations is dependent on their ability to identify, cultivate and exploit core competencies. Although directed at corporate level strategy, the definition of core competences *'the collective learning in the organization, especially as how to coordinate diverse production skills and integrate multiple streams of technologies; communication, involvement and a deep commitment to working across organizational boundaries'* could also be relevant at an operational level[31].

Other tangential developments of the RBV have seen the conception of a *'capability-based competition'* view (Stalk *et al.*, 1992). Similarly to the core competences model, the authors argue corporate success is dependent on the identification and management of key business processes, this time classified as *'capabilities'*. However, Stalk *et al.* (1992) argue there is a fundamental difference between the two paradigms, suggesting *'core-competences emphasize technological and production expertise at specific points along the value chain'* whereas

[31] The use of corporate level strategy theory at a business/operational level has been identified by other authors such as Foss (1997) who suggested Andrews' (1971) Corporate Strategy work was equally applicable at the business unit level.

'capabilities are more broadly based encompassing the entire value chain'. Again, as with the core competences concept, capabilities could possibly be relevant at an operational level. For example in respect of this examination, Stalk *et al.* (1992) argue successful application of their capabilities concept will be realised by '*...companies who combine scale and flexibility to outperform competition...*'.

6.2.2 RBV Criticism

In the context of operations management literature, the IO external market perspective is seen as counter-intuitive to the now prominent RBV view (Bourne *et al.*, 2003). However, the RBV is not without problems, De Toni and Tonchia (2003) argue the RBV is a controversial branch of research with other criticisms questioning its use as a practical management tool (Hoopes *et al.*, 2003) and as an actual theory (Priem and Butler, 2001a; 2001b). For example, suggesting RBV is an emergent perspective with many unsolved problems which need clarification, Foss (1997) and Nanda (1994) warn there is a considerable amount of terminological soup in the extant RBV literature with theorists using concepts such as *Resources*, *Competences* and *Capabilities*, for what is often essentially the same thing.

Bourne *et al.* (2003), in a recent special edition of the *International Journal of Operations and Production Management* dedicated to the RBV, argue there is a general paucity of literature available for practitioners suggesting there are very few cases available which make the RBV useful for practising managers. Hoopes *et al.* (2003), also in a recent special edition of the *Strategic Management Journal* dedicated to the RBV, concur suggesting RBV empirical work does exist but has not evolved in the accretive way theoretical literature has. Quantifying, Hoopes *et al.* (2003) present data arguing that less than 4% of RBV work published in six relevant journals contain a research design that tests two or more of the core premises of the RBV theory.

Theoretical criticisms focus on tautology, for example, Priem & Butler (2001a; 2001b) argue the definition that only valuable resources can be sources of competitive advantage is illogical as this is the feature of valuable resources themselves.

6.2.3 RBV: Future Developments

Reviewing the evolution of the RBV since its conception 10 years earlier, Wernerfelt (1995) looks to its future development as a functional tool and suggests that *"to make the resource-based view more useful we need to map the space of resources in more detail"*. Mills and Platts (2003) agree suggesting that what has not yet been presented in the literature is a useful framework for realising what resources and competences the firm has.

The paucity of extant empirical RBV literature combined with a shortage of practical frameworks for identifying resources, competences and capabilities leaves the RBV prime for further research. As Voss (2005) suggests, the RBV is ripe for research with many unanswered questions including how rare and imitable resources can be identified and developed. Operationalising the RBV concepts consistently across firms will also help overcome the tautology criticism (Hoopes *et al.*, 2003) by validating theory with data rather than validating theory with discussions on definition (Barney, 2001; Priem and Butler, 2001a; 2001b).

6.3 Economic Strategy, RBV & Lean

The link between lean, RBV and economic strategy can be made through the theories presented by Penrose (1959) who suggested resources bundled together render a service as an input to a production process and any of these unused productive services are a waste, that they are potentially free and therefore, if used profitably, can provide competitive advantage. The same link can be made by Teece (1980) who argues:

> *"Diversification can represent a mechanism for capturing integration economies associated with simultaneous supply of inputs common to a number of production processes geared to distinct final product markets"*.

Penrose (1959) and Teece (1980) identify a missing element from Womack *et al.*'s (1990; 1996b; 2005b) lean concept; the bundles of resources in a lean firm are treated as immiscible and the focus of efficiency is through optimising processes in a single value stream ignoring the opportunity to fully utilise resources required by the firm to fulfil its overall business objectives. This links the ideas informing the lean resources framework and RBV to the second stream of research, economic strategy theory.

Typically firms employing economies of scale strategies will receive rents[32] through high efficiencies utilising mass production techniques maximising available capacity through building to stock/forecast (Chandler, 1990a; 1990b). Firms employing economies of scope must achieve multi-product efficiencies through flexibility, utilizing available capacity (Chandler, 1990a). Therefore, to achieve economies of scale you do not have to achieve economies of scope but to achieve economies of scope you must be able to achieve economies of scale (Husan, 1997). Linking Penrose's (1959) theory of the firm to the economic theory suggests to achieve economies of scope the bundles of resources must be fully utilised otherwise there is waste present and economies of scope and scale are not realised.

6.3.1 Economies of Scale and Scope

Chandler (1990a; 1990b) introduces economy of scale as the cost advantages realised by large plants who can produce products at lower costs than small plants because the cost per unit will drop as the volume of output increases. Counterintuitive to economy of scale rational, Panzar and Willig (1975) coined the term economies of scope to describe cost savings realised when it is cheaper to combine two or more product lines in one firm rather than producing them separately. Goldhar and Jelinek (1983) suggest economies of scope focus on efficiencies through variety rather than economies of scale where efficiency is brought by volume. Chandler's (1990a) definition is more specific and describes economies of scope as efficiencies realised when large plants can use:

> *"many of the same raw and semi-finished materials and intermediate production processes to make a variety of different products"*

Important to this discussion and related to Penrose's (1959) theory of the firm and antecedent theories of multi-product firms (Clark, 1923; Clemens, 1958), Panzar and Willig (1981) argue:

> *"the origins of the multi-product firm spring from the opportunity to exploit some type of excess capacity".*

Combining scale and scope is important to realise cost advantages and Chandler (1990a) argues:

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[32] "Rents" is the term used in economic strategy literature to represent profitable income.

"the potential cost advantages (of scale and scope) can be fully realized if the flow[33] *of material through the plant can be kept constant to assure capacity utilization".*

Husan (1997) concurs arguing economies of scale are an essential determinant to achieving high levels of flexibility (scope) in particular to achieve:

"minimum efficient scales of manufacturing".

This argument is validated by Karlsson (1996) whose collaborative study with Volvo found a joint venture with Mitsubishi was established to allow Volvo to achieve both economies of scale and scope for their exclusive products. Swamidass *et al.* (2001), in another case example, found businesses were using economy of scope flexibilities as a strategic tool for achieving sustained competitive advantage. Similarly, Offodile (1992) argues grouping products that are similar in their production sequences or geometry, rather than grouping technologies, allows efficiencies to be achieved through scale and scope economies.

At this point in the discussion a working definition of flexibility will be useful to further develop the economy of scale and scope concepts and relate them to the development of a lean resource mapping framework. Oke (2005) suggests although taxonomies of flexibility have been suggested there is confusion and the concept is not fully understood. Synthesising antecedent definitions of flexibility (Slack, 1983; 1991; Holweg and Pil, 2001), Holweg (2005) presents a useful definition of flexibility -in the context of operations management research- which will be used for the purpose of this investigation:

"Flexibility: is a generic ability to adapt to internal and/or external influences".

With a working definition of flexibility it is now possible to develop the concepts of scale and scope into a useful model for relating the framework to other manufacturing systems. Reconfiguring Krafcik's (1988) 'categorisations of production systems' model as presented in Chapter 3, Figure 33 shows the position

[33] Flow is one of the key objectives of the lean concept Womack and Jones (1996). In the context of mass production flow can only be achieved when there are large volumes of the same product using the same components over a long period of time as in the case of the Ford Model T. It was Ohno (1988) who developed the Toyota Production System to create continuous flow in smaller scale production lots where the focus was on quick changeovers from one product to another.

of the production systems in relation to economies of scale and economies of scope brought up to date with the inclusion of Build-To-Order[34] (Monden, 1983; Hall and Tonkin, 1989; Hall, 1993; Holweg and Pil, 2001; 2004) as introduced in the lean literature review in Chapter 3 as presented by the Author.

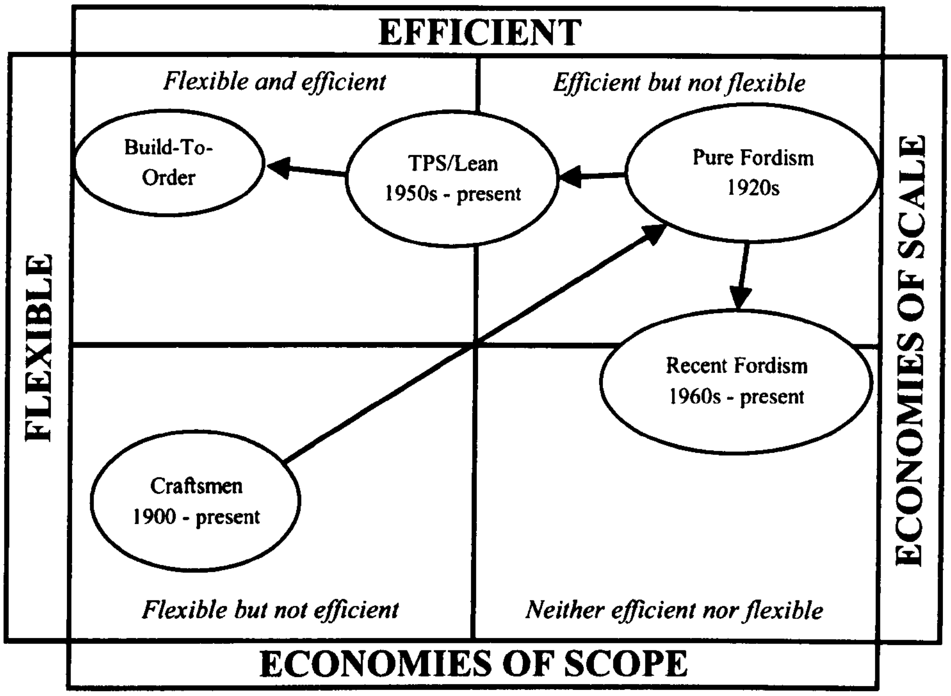

Figure 33: Scope & Scale Model for Manufacturing

Reviewing the scale and scope model, production systems first started with Craftsmen[35] who specialised in manufacturing bespoke products in small quantities (usually one off). In the context of the model they are highly flexible but not efficient delivering high levels of scope but low levels of scale.

The first major development of production systems is made by Ford who introduced the concept of mass production, breaking down the stages of manufacturing into simplified steps focusing on delivering the exact same product with the minimum of waste. In the context of the model Ford's focus on efficiency through scale with no flexibility of products is the antithesis of the Craftsmen production system because of its high levels of scale and low levels of scope.

[34] Build-To-Order in this context is the same as mass customisation (Pine, 1993) with every product bespoke rather than standard products that can also be Built-To-Order (Holweg and Pil, 2001, 2004)
[35] This is in the context of the automotive industry, craftsmen had previously worked in other industries before such as textile and armoury industries (Chandler ,1990).

The next development of production systems is split into two directions. First, recent Fordism incorporates high levels of stock in an attempt to deliver flexibility of products resulting in a reduction in economies of scale and with a marginal improvement in levels of scope[36]. The second development is made by Toyota who created the Toyota Production System (TPS) in an attempt to combine early Ford efficiency with Craftsmen flexibility. In the context of the model, TPS is highly efficient and flexible with high levels of scale and good levels of scope.

The final production system is Build-To-Order where, in this context, every product is bespoke and production is highly flexible and efficient. The BTO system combines the best of the Craftsmen system (flexibility and scope) with the best of the early Ford system (efficiency and scale) to achieve high levels of efficiency, flexibility, scale and scope.

6.4 Developing a Theoretical Framework for an Eighth Waste

One of the core principles informing the lean theoretical framework is the elimination of non-value adding waste in product based process driven value streams (Womack and Jones, 1996a; 1996b). Value Stream Mapping (VSM) tools have been developed (Womack and Jones, 1996b; Hines and Rich, 1997; Rother and Shook, 1998; Hines *et al.*, 2000; Jones and Womack, 2003) as static analysis tools for identifying and quantifying the seven wastes of lean as defined by Ohno (1988). This conceptual framework argues the criticisms of the lean concept (Turnbell, 1988; Garrahan and Stewart, 1992; Cusumano, 1994; Williams *et al.*, 1992; 1994; Katayama and Bennett, 1996; Lamming, 1996; Ward, 1996; Maccoby, 1997; Rinehart *et al.*, 1997; Pilkington, 1998; Green, 1999; Lewis, 2000; Lawson, 2001; Smart *et al.*, 2003; Hines *et al.*, 2004) can be overcome by developing a more holistic and dynamic triangulated framework (Jick, 1979) which includes qualitative waste analysis completory to the extant quantitative data (from VSM).

At the core of the completory framework is the identification and elimination of an 8th waste. The idea of a qualitative 8th lean waste -to add to Ohno's (1988) taxonomy- has been discussed in the lean literature but there are many different descriptions. For example, Suzaki (1993) proposes the 8th waste is simply *"...not*

[36] This lack of scope with high levels of stock is due to a paradox identified by Taiichi Ohno (1988) who suggested the more inventory a company has, the less likely it is that they will have what they need.

utilising people's talent" or *"underutilizing people's skills and capabilities"* (Suzaki, 1987). Womack and Jones (1996) initially proposed the 8th waste was *"the design of goods which do not meet users' needs"* and later updated this to *"the under utilisation of employees"* (Womack & Jones, 2003). Liker (2004), an academic specialising in the Toyota Production System, suggests the 8th waste is *"unused employee creativity. Losing time, ideas, skills, improvements, and learning opportunities by not engaging or listening to your employees".*

All of the suggested 8th wastes infer a softer more qualitative understanding is required to complement the extant taxonomy which is much harder and quantitative. This investigation proposes an 8th waste introduced as *polarisation,* the polarisation of resources in relation to *products, processes, people* and *plant* building on the theories of vertical and horizontal polarisation proposed by Kelly (2001). Polarisation is chosen as a deliberately abstract title to enable the concept to be applied across a broad range of subjects as have other authors when applying Ohno's (1988) 7 wastes (Hines and Rich, 1997; Hines *et al.*, 2000; 2004; Suzaki, 1993; Liker, 2004; Womack and Jones, 1996a; 1996b; 2005a; 2005b).

Taking a holistic approach to developing a lean resource framework, the 8th waste is seen as a core element for operationalising the conceptual framework in parallel to the extant lean taxonomy. Developing the conceptual framework further, to encompass a holistic view of the firm, the theories informing the RBV provide a useful platform to build from. Typically the RBV has been used as a lens to understand sources of competitive advantage (Barney, 1991; 2001; Grant, 1991; Peteraf, 1993) between firms. More specifically the RBV argues, those firms achieving external heterogeneity; imperfect resource mobility; sustainable cost advantages and financially justifiable implementation costs will achieve above normal returns (Peteraf, 1993). However, the RBV dimension of heterogeneity is criticised as being tautological (Priem and Butler, 2001a; 2001b) as inherent firm disparity will always provide differing levels of performance.

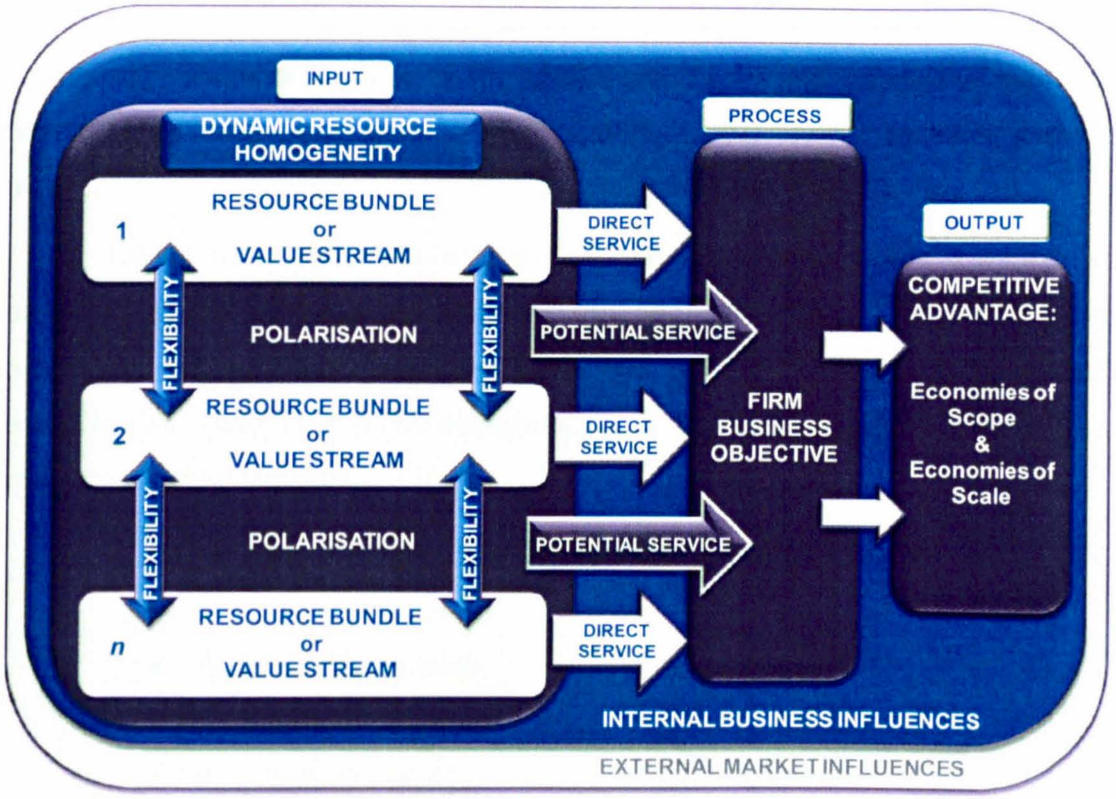

Figure 34: Lean Resource Conceptual Framework

Overcoming the tautology criticism, the lean resource framework presented by the Author in Figure 34 argues the RBV focus should shift from external firm heterogeneity to an internal focus of dynamic resource homogeneity. As has already been suggested, Penrose (1959) and Teece (1980) identify a missing element from Womack *et al.*'s (1990; 1996b; 2005b) lean concept where typically the bundles of resources in a lean firm are treated as immiscible and the focus of efficiency is through optimising processes in a single value stream ignoring the opportunity to fully utilise resources required by the firm to fulfil its overall business objectives.

Counterintuitive to the normative product based value stream focus, the conceptual framework argues homogeneity across process driven value streams, rather than heterogeneity between them, will deliver bundles of potential services to the overall firm business objectives allowing for both economies of scale and scope to be realised and subsequent competitive advantage to be gained.

6.5 Developing a Lean Resource Mapping Framework: Case Study Examples

6.5.1 Introduction

The lean resource mapping framework follows a sequential data gathering methodology compiling information through observation of work practices; one-to-one interviews with employees; group discussions and documentation analysis. A preliminary fieldwork study gave the opportunity to develop provisional standard templates adapted from Kelly's (1988; 1997; 2001; 2005) business centred maintenance engineering framework[37] later tested and refined in industry.

Taking a holistic view of the firm, the framework builds towards the development of a lean resource matrix showing the "current state"[38] of resources in relation to the products, processes, plant and people employed. Primary data collection was carried out at two manufacturing facilities utilising the following lean resource mapping template:-

- Business overview including operations strategy adopted
- Site layout diagram
- Asset specificity table
- Process flow diagram
- Responsibility matrix
- Personnel inventory list
- Administrative structure
- Lean resource matrix

The following sequence of activities summarises the lean resource mapping process. The first stage in the process is the detailed understanding of the business operations strategy adopted setting a platform for the subsequent lean resource mapping. The site layout diagram is used to provide a useful overview of the scale of operations and location of manufacturing equipment and storage areas. The next step is the development of an asset specificity table summarising the details of each grouping of similar assets by their production applications. Assets are tabulated under the following criteria: a group name[39]; their location in the facility; a description of their exact production function(s); the quantity of assets in the specific

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[37] Professor Kelly originally developed the framework whilst working at Manchester University School of Engineering in partnership with industrial organisations. A visit was made to Manchester University to discuss the opportunity of developing the framework for use in manufacturing operations. As Professor Kelly had retired from academia the meeting was held with Dr Andrew Starr who is a Senior lecturer at the school teaching Professor Kelly's work. It was agreed the framework was adaptable and a copy of Professor Kelly's PhD thesis was made for reference purposes.
[38] Current state is a term used in lean value stream mapping to indicate a snapshot of the extant practices within the business of focus.
[39] As defined by the production strategy, organisation and structure.

group; and the shift pattern they are operated under. The asset specificity table is referred to in the development of a more detailed plant layout diagram and in the development of the process flow diagram and lean resource matrix.

Taking information from both the plant layout drawing and the asset specificity table there are now sufficient data to draw a process flow diagram indicating the structure of product manufacture from when raw materials are shipped in to when finished goods are shipped out. The process flow diagram can also be used to give a snapshot overview of processes operating at multi levels of the company. Before the lean resource matrix can be developed details of the people management strategy must be captured. Switching the data collection focus away from plant, products and processes to people, the responsibility matrix is introduced as a first step in the accumulation of data facilitating an overview of the personnel strategy employed.

Taking information from the site layout drawing, asset specificity table and process flow diagram, the responsibility matrix shows which manager/supervisor is accountable for each of the different process stages in product manufacture. Supplementing the data collected within the responsibility matrix, the personnel inventory list details the exact level of employees and their function within the business. For analysis purposes the inventory list typically splits personnel into three main categories: supervisory, skilled and unskilled personnel.

Merging the information taken from the responsibility matrix and the personnel inventory list there are now sufficient data to draw up the administrative structure of the business. The administrative structure illustrates the relationship between different functions and their departmental positioning within the organisational structure. Taking data from the site layout drawing, asset specificity table, process flow diagram, responsibility matrix, personnel inventory list and administrative structure, there is sufficient information to compile the lean resource matrix.

The next two sections present the case study data collected from the two manufacturing facilities referred to as Company X and Company Y.

6.5.2 Company X Case Study Data

The following sub-sections show the results of the lean resource mapping process at Company X. In each sub-section the template application is explained and examples are presented.

Business Overview Including Operations Strategy Adopted

Company X operates within the fast moving consumer goods (FMCG) market sector of the UK manufacturing industry specialising in the manufacture and assembly of aerosol valve assemblies and aerosol actuators. Products are manufactured and distributed through a central facility to customers within the UK with some components parts additionally manufactured in bulk for shipment around the world to other divisions of the parent corporation. Main customers include household names such as Unilever Faberge and Proctor and Gamble who sell 1000's of permutations of aerosol-based products such as deodorants and hair sprays to consumers.

Company X is currently the largest manufacturer of aerosol valves in the world with annual revenues of over $280 million producing 5 billion valves during 2004. The company founder developed and patented the first re-usable mass produced aerosol valve in 1949. This revolutionary valve design created an entirely new dispensing mechanism that was immediately well received throughout the industry and was seen as the technology of choice for an entire class of consumer products. The success resulted in the rapid expansion and development of the business. Today, the company operates plants in six continents and 20 countries and is the only global manufacturer of aerosol valves.

The main processes employed at Company X include: aerosol valve spring coiling; aerosol valve stem and valve housing injection moulding; aerosol actuator injection moulding; aerosol dip tube extrusion; aerosol valve stem and housing hole lasering; aerosol valve assembly; dip tube and aerosol valve assembly; and finally, aerosol actuator assembly. Components parts are processed in large batch quantities which are held in a central store and redistributed to downstream processes as required. Processing techniques and machinery range from 20-30 year old manually operated assembly and production equipment to the latest technology incorporating fully integrated and automatic processing plant. Company X could be described as operating a non-lean approach to its manufacturing and operations processes.

Site Layout Diagram

The site layout diagram provides a useful overview of the scale of operations and location of manufacturing equipment and storage areas. Figure 35 shows the simplified layout diagram for the manufacturing facility of Company X.

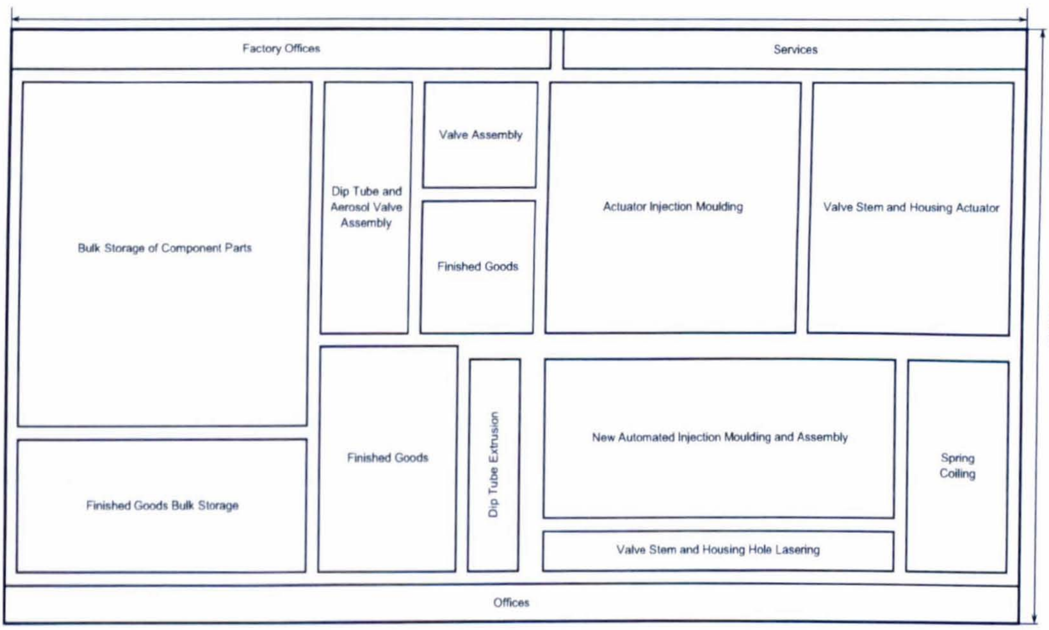

Figure 35: Company X Plant Layout

As more data is collected during the lean resource mapping process, further detail can be added to the layout drawing. For example, Figure 36 shows a more detailed layout of the injection moulding machine (IMM) sections including details of plant specificity, plant asset numbers and the shift patterns the plant is operated under.

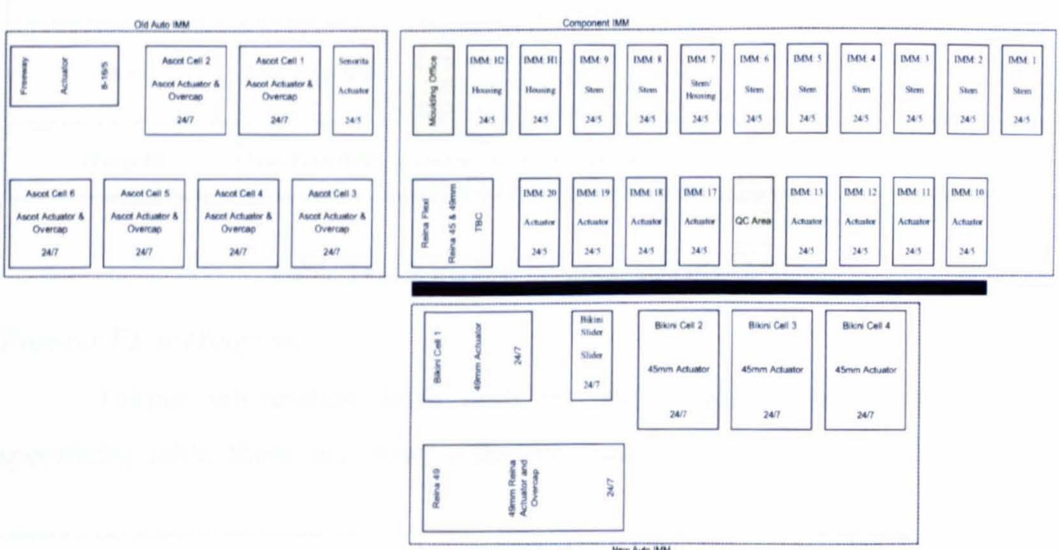

Figure 36: Company X Injection Moulding Machine Sections

Asset Specificity Table

The asset specificity table summarises the details of each grouping of similar assets by their production applications. Assets are tabulated under the following criteria: a group name[40]; their location in the factory; a description of their exact production function(s); the quantity of assets in the specific group; and the shift pattern they are operated under. The asset specificity table is referred to in the development of a more detailed plant layout diagram as has been shown in Figure 36. Also, the table is referred to in the development of the process flow diagram and lean resource matrix.

Focusing on the injection moulding machinery and any supplementary equipment, Table 14 shows an example of an asset specificity table. For example, the Ascot mould group is situated in the old automatic section where there are 6 similar automated assembly cells moulding aerosol actuators and assembling pre-supplied aerosol valve inserts and actuator body over-caps on a 24 hours a day, 7 days a week shift pattern.

Mould Group Name	Location	Description	Number of IMMs	Shift Pattern
Ascot	Old Auto IMM	6 Automatic Cells moulding actuators and fitting pre-moulded inserts and over-caps	6	24/7
Freeway	Old Auto IMM	1 Automatic cell moulding actuators and fitting pre-moulded inserts	1	8-16/5
Senorita	Old Auto IMM	1 IMM moulding actuators	1	24/5
Stem/Housing	Component IMM	11 IMM moulding stems and housings	11	24/5
Actuator	Component IMM	8 IMM moulding actuators	8	24/5
Reina Flexi Cell	Component IMM	1 IMM moulding actuators and fitting pre-moulded inserts and over-caps	1	TBC
Bikini	New Auto IMM	4 automatic cells moulding actuators and fitting pre-moulded sliders (moulded in cell) and pre-moulded inserts	5	24/7
Reina 49	New Auto IMM	1 automatic cell moulding actuators and over-caps and fitting pre-moulded inserts	2	24/7
			35	

Table 14: Company X Asset Specificity Table

Process Flow Diagram

Taking information from both the plant layout drawing and the asset specificity table there are now sufficient data to draw a process flow diagram

[40] As defined by the manufacturing strategy, organisation and structure.

indicating the structure of product manufacture from when raw materials are shipped in to when finished goods are shipped out. Figure 37 shows the process flow diagram for Company X incorporating production processes and plant services. Focusing on the valve manufacture it can be seen there are three main processing stages operating in series between raw materials and finished goods.

During the first stage component parts are produced using four processes operating in parallel: valve spring coiling; valve stem injection moulding; valve housing injection moulding and finally dip-tube extrusion. The second stage incorporates two processes operating in parallel: stem assembly is shown in series with stage one's valve spring coiling and valve stem injection moulding; hole lasering is shown in series with stage one's valve housing injection moulding. Finally the component parts, sub-assemblies and bought in components are assembled in stage three before shipment to the customer or storage in the bulk warehouse.

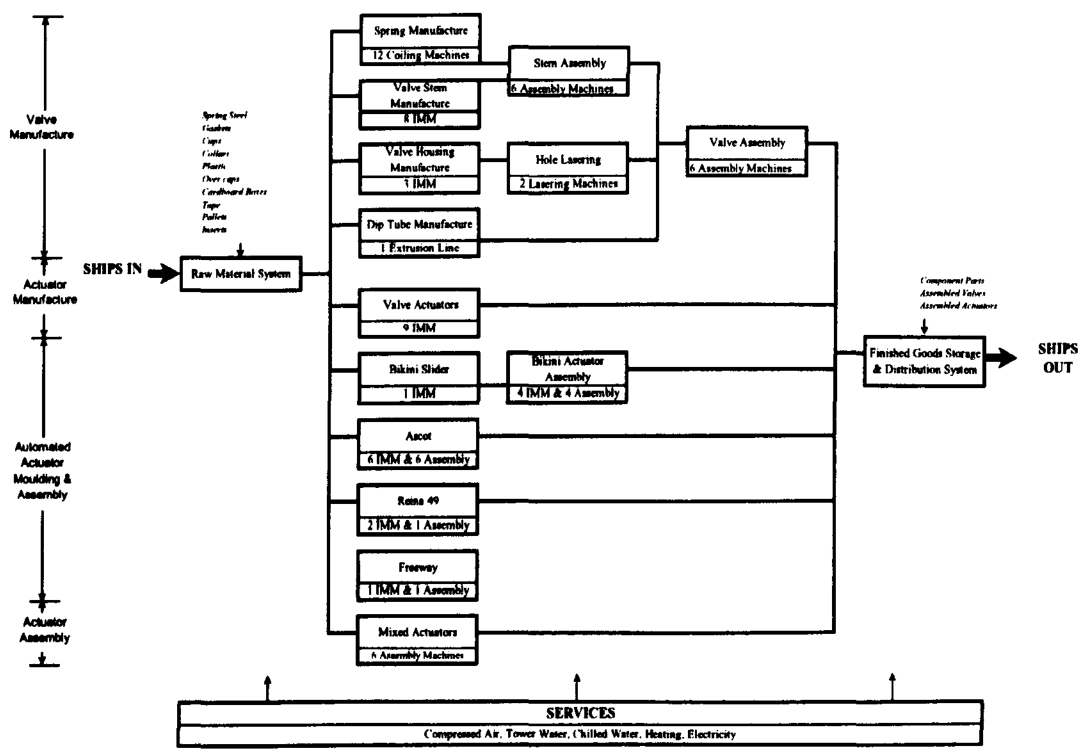

Figure 37: Company X Process Flow Diagram

The process flow diagram can also be used to give a snapshot overview of processes operating at multi levels of the company.

Responsibility Matrix

Before the lean resource matrix can be developed details of the people management strategy must be captured. Switching the data collection focus away from plant, products and processes to people, the responsibility matrix is introduced as a first step in the accumulation of data facilitating an overview of the personnel strategy employed. Taking information from the site layout drawing, asset specificity table and process flow diagram, the responsibility matrix shows which manager/supervisor is accountable for each of the different process stages in product manufacture.

Figure 38 introduces the responsibility matrix for company 'X's operations departments showing the individual steps in the production process in relation to the manager responsible for that particular step. For example, the injection moulding machine manager is shown as responsible for the valve stem injection moulding; valve housing injection moulding; valve actuator injection moulding; Bikini injection moulding and assembly cell; Ascot injection moulding and assembly cell; Reina 49 injection moulding and assembly cell; and finally the freeway injection moulding and assembly cell.

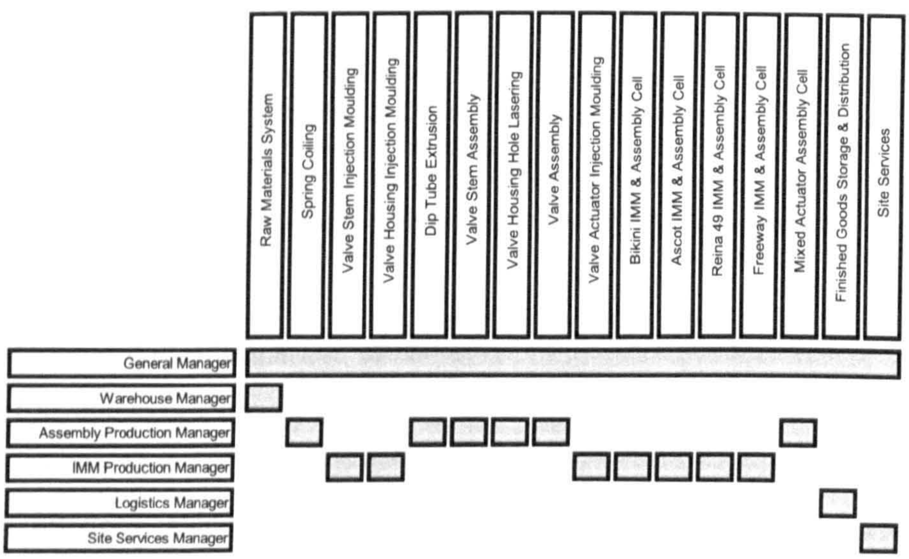

Figure 38: Company X Responsibility Matrix

Personnel Inventory List

Supplementing the data collected within the responsibility matrix, the personnel inventory list details the exact level of employees and their function within the business. For analysis purposes the inventory list typically splits personnel into three main categories: supervisory, skilled and unskilled personnel. An example of the personnel inventory list is shown in Table 15 which details the personnel employed within the injection moulding department specifying the skilled personnel as setters[41] and the unskilled personnel as operators[42].

Additional information can be included in the personnel inventory list such as the work/shift patterns. For example, there are 10 senior setters shown in the IMM personnel inventory list, 6 work a 24/5[43] shift pattern and 4 work a 24/7[44] shift pattern. This additional information will be useful in the development of the lean resource matrix.

Supervisory	
Moulding Manager	1
Assistant Moulding Manager	1
Training Co-ordinator	1
Trainee Training Co-ordinator	1
Co-ordinator	1
Sub Total	***5***
Setters	
Senior 24/5	6
Senior 24/7	4
Setter 24/5	6
Setter 24/7	4
Trainee Setter	3
Sub Total	***23***
Operators	
QC 24/5	6
QC 24/7	4
General 24/5	30
General 24/7	20
Sub Total	60
Grand Total	***88***

Table 15: Company X IMM Personnel Inventory List

Administrative Structure

Merging the information taken from the responsibility matrix and the personnel inventory list there are now sufficient data to draw up the administrative structure of the business. The administrative structure illustrates the relationship between different functions and their departmental positioning within the

[41] 'Setter' is a job title given to personnel with specialist skills in a given process. In this instance the setters are specialists in the injection moulding processing.
[42] 'Operator' is a job title given to personnel with limited skills who carry out simple and repetitive work activities.
[43] In this instance 24/5 refers to a shift pattern covering 24 hours a day, Monday to Friday inclusively. To cover the 24 hour period there are 3 different shifts working for 8 hours each: 6-2, 2-10 & 10-6.
[44] In this instance 24/7 refers to a shift pattern covering 24 hours a day, Monday to Sunday inclusively. To cover the 24 hour period there are 4 different shifts working for 12 hours each on a rotating basis: 06:00hrs – 18:00hrs & 18:00hrs to 06:00hrs

organisational structure. For example, Figure 39 shows the administrative structure at a senior management level only giving an overview of the departmental structure within the organisation.

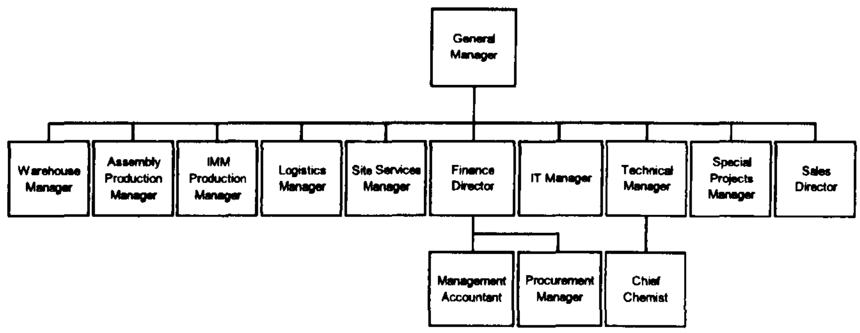

Figure 39: Company X Senior Management Administrative Structure

For the development of the lean resource matrix the administrative structure must also be detailed at a lower level of the organisation hierarchy taking a bottom-up approach. Figure 40 shows an example of the 'Bikini'[45] cell administrative structure including exact details of shift patterns worked by individuals.

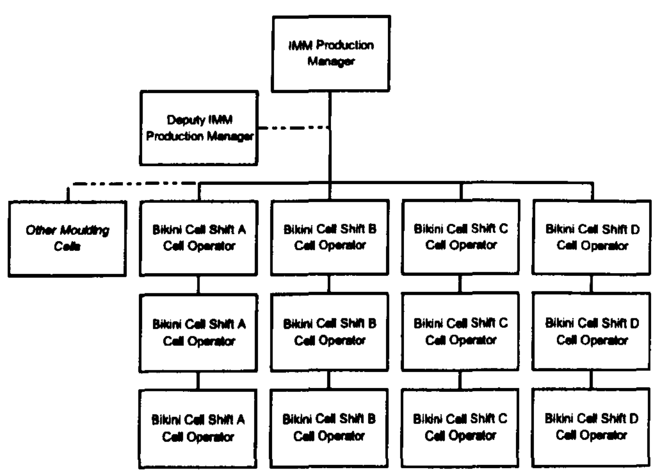

Figure 40: Company X Bikini Cell Administrative Structure

Lean Resource Matrix

Kelly (1988; 1997; 2001; 2005) introduces a framework developed to analyse maintenance engineering management systems. The argument is made that the framework is adaptable to use in general manufacturing operations as effective and efficient maintenance engineering systems are dependent on the ability to be responsive to unpredictable work (plant breakdowns) by utilising flexible resources

[45] Bikini in the project code name

(personnel, tools, knowledge). Kelly (1988; 2001) argues that if dynamic matching of the workforce to the workload is to be achieved, flexibility is the most desirable characteristic to be fostered. Elaborating further, Kelly presents a list of flexibilities that must be understood if dynamic matching is to be achieved:

- Maintainer-operator flexibility
- Inter-trade flexibility
- Inter-plant flexibility
- Flexibility of location
- Shift working flexibility
- Flexibility to use contract and/or temporary labour.

Operationalising the theory, Kelly (1988; 2001) introduces a resource structure mapping functionality (vertical axis) against plant/product specialization (horizontal axis).

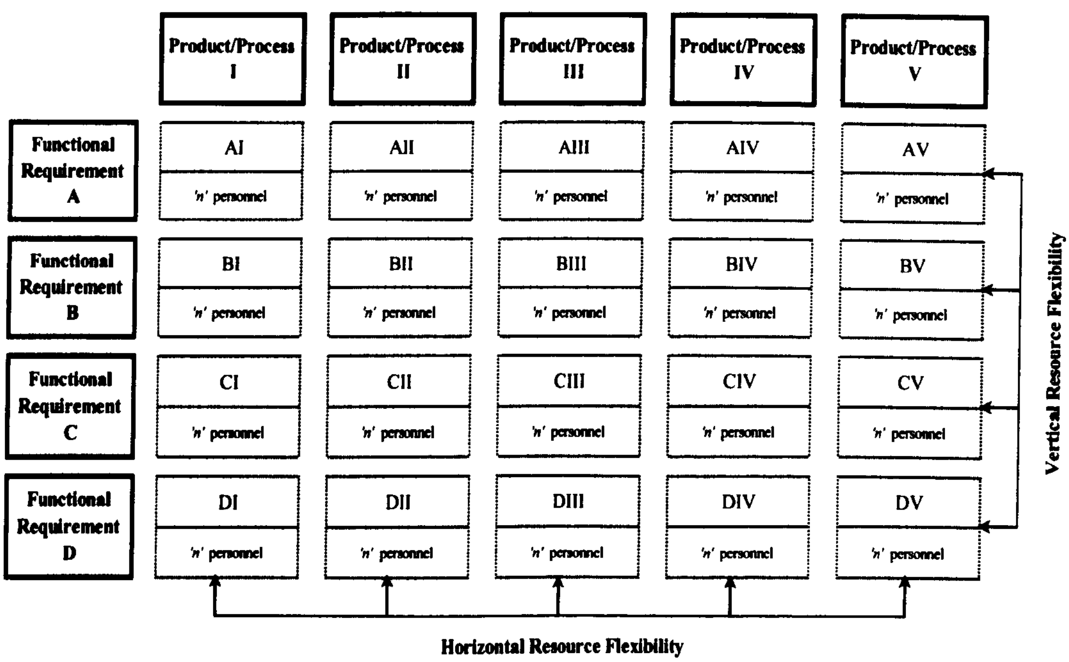

Figure 41: Lean Resource Matrix Template

The lean resource matrix developed by the Author (as shown in Figure 41), represents an adaptation of Kelly's (1988; 2001) resource structure and Wernerfelt's (1984) resource-product matrix. The framework shows how functional requirements (FR) and product/processes/plant (PPP) are resourced enabling the identification of extant flexibility levels. For example, the interface of PPP '*I*' and FR '*A*': '*AI*' is resourced by '*n*' personnel. The model is useful to understand whether resource '*AI*' is horizontally flexible covering other PPPs such as *II, III, IV* and *V;* or vertically flexible covering other FRs such as *B, C* and *D.* Vertical polarisation may occur when there is little or no flexibility of resources between functional requirements. Similarly, horizontal polarisation may occur when there is little or no flexibility of resources between products/processes.

Taking data from the site layout drawing, asset specificity table, process flow diagram, responsibility matrix, personnel inventory list and administrative structure, there is sufficient information to compile the lean resource matrix for Company X.

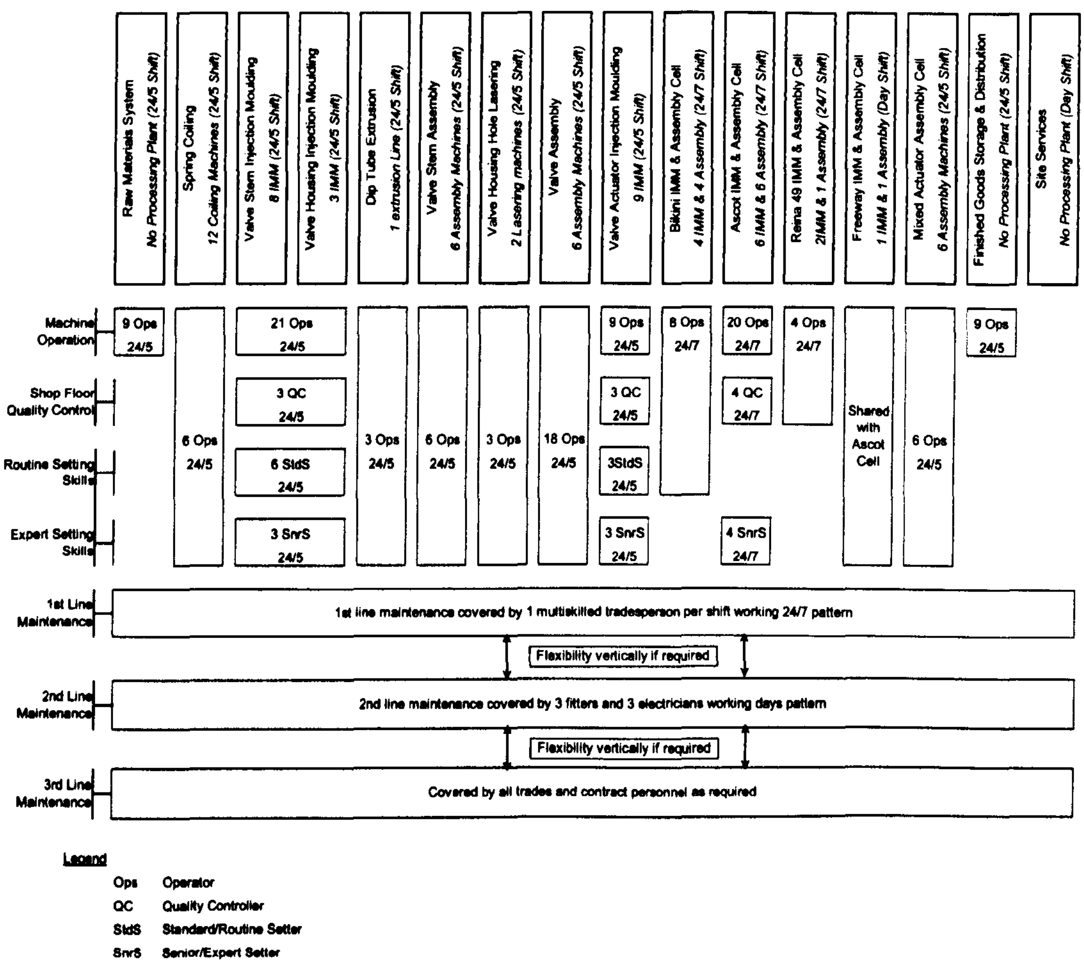

Figure 42: Company X Lean Resource Matrix

Figure 42 presents the operations level lean resource matrix for Company 'X'. At this level it is possible to see the overall strategy adopted for manufacturing operations. For example, the 1st, 2nd and 3rd line maintenance functional activities are shown vertically polarised from the operation, quality control and setting functions. Reviewing the resource alignment shown in Figure 42 there is also a distinct horizontal polarisation between the production stages with very little overlap or flexibility of resources shown. At lower levels of lean resource mapping it is possible to look in more detail at these relationships. These two forms of polarisation are key elements in the lean resource mapping framework and will be discussed in more detail in the next sub-section.

6.5.3 Company Y Case Study Data

The following sub-sections show the results of the lean resource mapping process at Company Y. As the template design has already been explained this section only includes examples of data collected with clarification of detail explicated as required.

Business Overview Including Operations Strategy Adopted

Company Y operate within the 1st tier automotive component market sector of the UK manufacturing industry specialising in the manufacture of automobile gearbox internal components. Products are manufactured and delivered just-in-time[46] (JIT) to the customer on a daily basis with very limited (3 days) stock kept. Sets of components are manufactured and delivered in quantities matching the exact production rate at the customer's vehicle assembly plant[47]. Company Y could be described as operating a lean approach to its manufacturing and operations processes.

Company Y has been set up as a joint venture between a leading Japanese automobile manufacturer, one of its key suppliers in Japan and a UK supplier of component parts to the automobile industry. The internal gearbox components manufactured are produced to very tight engineering tolerances and their overall precision is critical to the reliability of the finished product. This criticality has meant that previously all gearbox internals have only been manufactured at either the vehicle suppliers' main facility or at trusted suppliers both situated in Japan.

The main processes employed at Company Y include: turning, pick and place robotics, drilling, gear hobbing, gear shaping, gear shaving, heat treatment, honing, grinding and gear profile measurement. Components parts are processed in small batch quantities which move through the factory with very little work in progress.

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[46] JIT was developed by Taiichi Ohno to streamline the value stream between customer and supplier at Toyota. The system developed was based on the American supermarket where product replenishment (shelf stock) is driven by customer demand (Womack and Jones, 1994).
[47] The customer also only builds vehicles based around customer demand and at this point the average vehicle sales for the models relevant to this study was 170 vehicles per day.

Company Y was set-up on a brown field site[48] with £10 million of capital investment split between the three businesses. All assets were purchased from a Japanese machinery supplier previously used by both the Japanese businesses but new to the UK based component supplier.

Site Layout Diagram

Figure 43 shows the simplified layout diagram for the manufacturing facility of Company Y with the factory shown split into its 3 main production areas: gear manufacture, shaft manufacture and heat treatment.

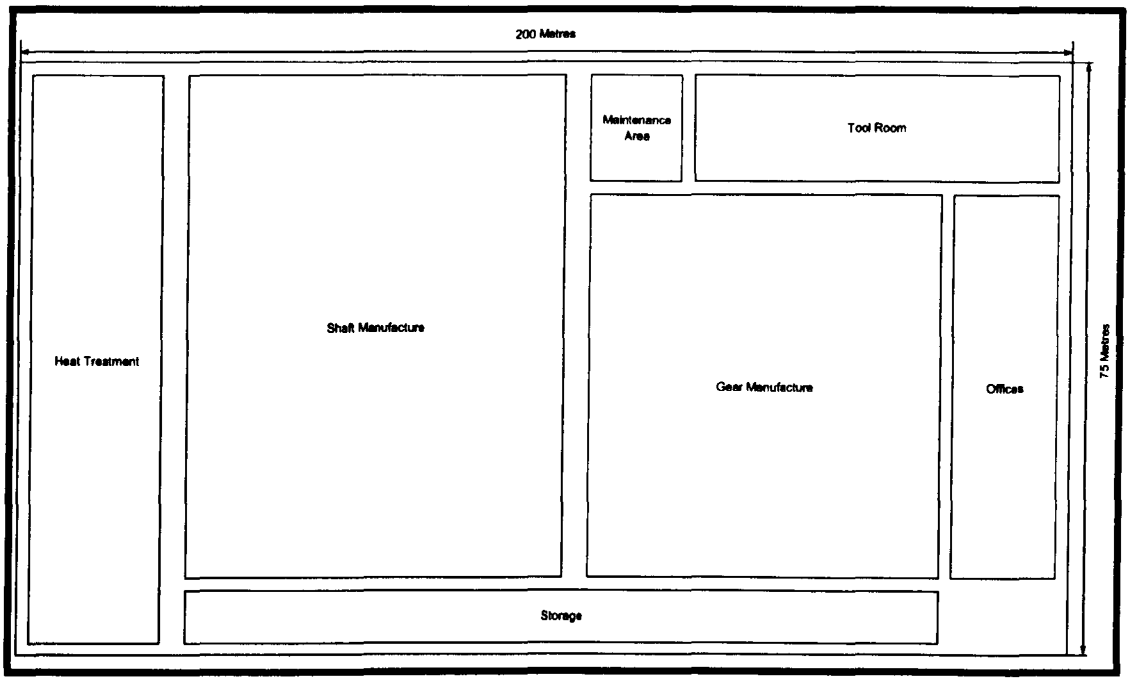

Figure 43: Company Y Plant Layout

Focusing on the gear manufacturing area, Figure 44 shows a more detailed view of the exact layout of the production plant splitting the area into 4 main production cells A, B, C & D. Each of the cells is split again into soft and hard machining as gears are hardened in the heat treatment section after soft machining.

[48] Brown field sites are defined as facilities that already exist but are stripped back to a basic shell for development. Existing personnel are usually transferred/utilised in the setting-up of the facility. This differs from a green field site where everything is set-up from new utilising new buildings, machinery and personnel.

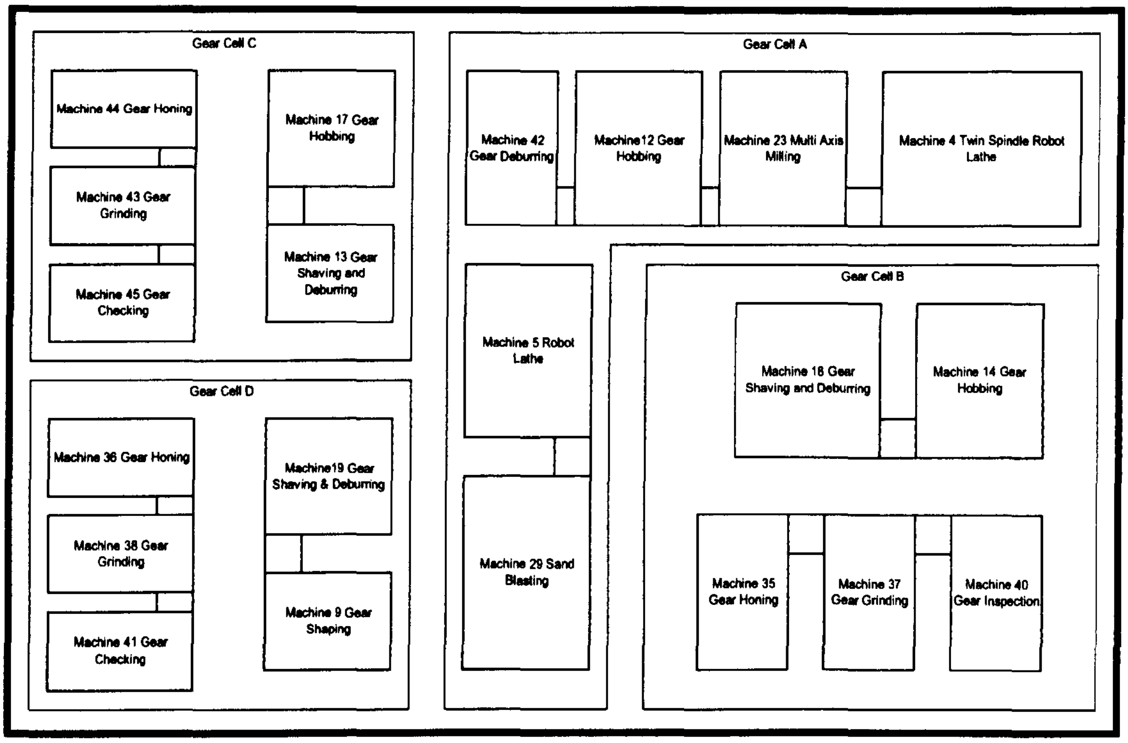

Figure 44: Company Y Gear Cell Layout

Asset Specificity Table

Focusing on the gear manufacturing cell Table 16 shows the asset specificity table for each of the soft and hard machining groups. For example, gear cell 'A' soft processes final driven gears from forged blanks through turning, drilling, gear hobbing and gear deburring processes on a 06:00-22:00hrs shift pattern, 5 days per week.

Group Name	Location	Description	Number of Machines	Shift Pattern
Gear Cell A Soft	Gear Cell A	Final driven gears soft machined from forged blanks including turning, drilling, hobbing and deburring.	4	06:00-22:00/5
Gear Cell A Hard	Gear Cell A	Final driven gears hard machined post heat treatment including finishing boring, inspection and sand blasting.	2	06:00-22:00/5
Gear Cell B Soft	Gear Cell B	Counter gears soft machined from pre turned forged blanks including gear hobbing, gear shaving and deburring	2	06:00-22:00/5
Gear Cell B Hard	Gear Cell B	Counter gears hard machined post heat treatment including honing, grinding and final inspection.	3	06:00-22:00/5
Gear Cell C Soft	Gear Cell C	Counter gears soft machined from pre turned forged blanks including gear hobbing, gear shaving and deburring	2	06:00-22:00/5
Gear Cell C Hard	Gear Cell C	Counter gears hard machined post heat treatment including honing, grinding and final inspection.	3	06:00-22:00/5
Gear Cell D Soft	Gear Cell D	Main gears soft machined from pre turned forged blanks including gear shaping, gear shaving and deburring	2	06:00-22:00/5
Gear Cell D Hard	Gear Cell D	Main gears hard machined post heat treatment including honing, grinding and final inspection.	3	06:00-22:00/5
			21	

Table 16: Company Y Asset Specificity Table

Process Flow Diagram

Figure 45 shows the process flow diagram for Company Y incorporating production processes and plant services. Focusing on the gear manufacturing it can be seen there are three separate processing stages operating in series between raw materials and finished goods. During the first stage component parts are produced in four soft machining cells operating in parallel. The second stage incorporates heat treatment in one of three blast furnaces. Finally the component parts are hard machined in four machining cells operating in parallel before being shipped directly to the customer.

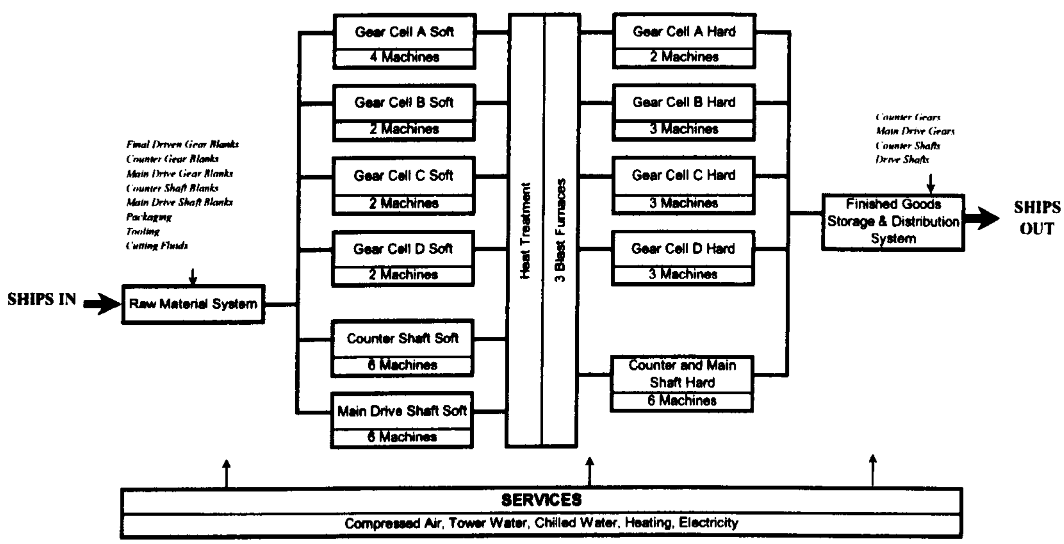

Figure 45: Company Y Process Flow Diagram

Responsibility Matrix

Figure 46 introduces the responsibility matrix for Company Y operation departments, showing the individual steps in the production process in relation to the manager responsible for that particular step. For example, the chief engineer is shown as responsible for the heat treatment and site services.

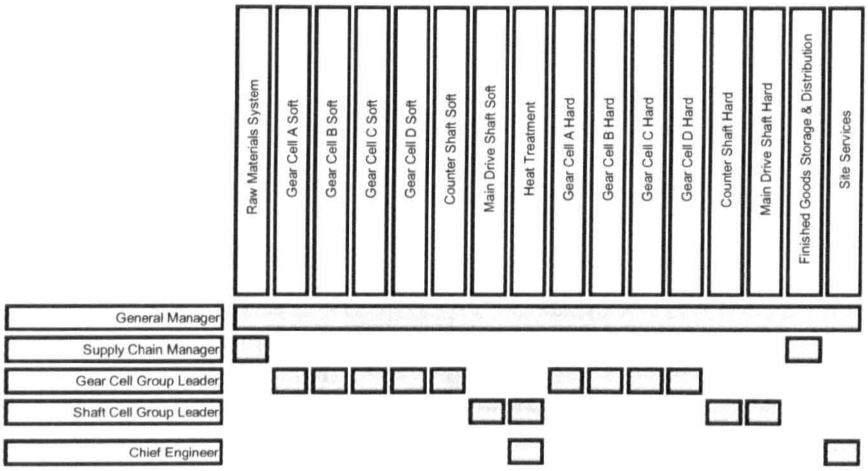

Figure 46: Company Y Responsibility Matrix

Personnel Inventory List

Table 17 details the personnel inventory list for the gear cells at Company Y. In this list there are only two categories as the personnel strategy at Company Y is to multi-skill production operators to carry out machine setting, machine maintenance and quality control functions along with machine operation duties.

Supervisory	
Group Leader	1
Shift Team Leader	2
Kaizen Engineer	1
Sub Total	***4***
Operator Maintainers	
Gear Cell A Soft & Hard	2
Gear Cell B Soft & Hard	2
Gear Cell C Soft & Hard	2
Gear Cell D Soft & Hard	2
Sub Total	***8***
Grand Total	***12***

Table 17: Company Y Gear Cell Personnel Inventory List

Administrative Structure

Figure 47 shows the administrative structure at a senior management level giving an overview of the departmental structure within the organisation at Company Y. Due to the criticality of the components being manufactured and the seminal nature of the plant's location, a shadow team of Japanese managers and engineers are incorporated into the structure.

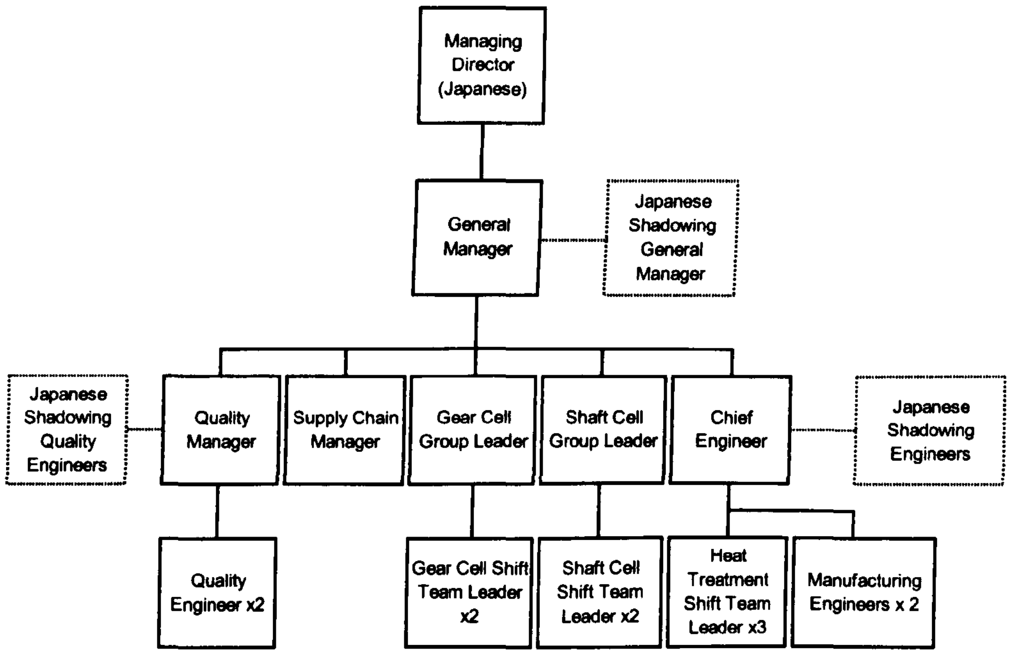

Figure 47: Company Y Senior Management Administrative Structure

Figure 48 shows an example of the gear cell administrative structure including details of the two shift system with each shift being controlled by a shift team leader responsible for 4 operator maintainers.

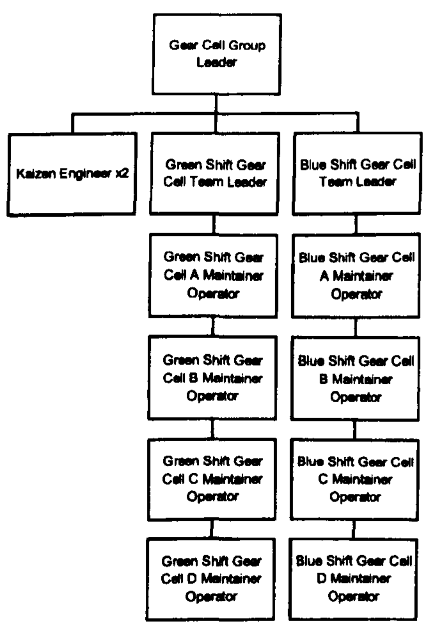

Figure 48: Company Y Gear Cell Administrative Structure

Lean Resource Matrix

Figure 49 presents the operations level lean resource matrix for Company Y. At this level it is possible to see the overall strategy adopted for manufacturing operations. For example, the 1st line maintenance functional activities are shown integrated into the plant operation function indicating an adoption of a TPM strategy towards asset management.

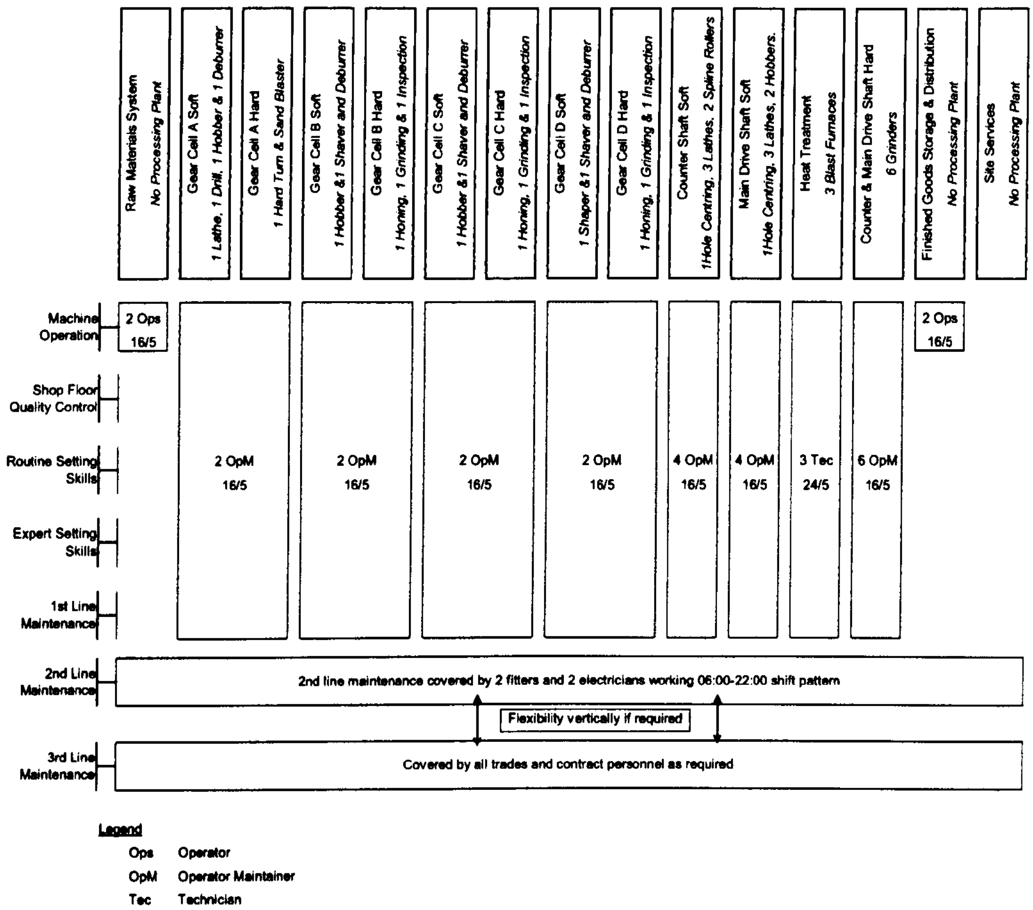

Figure 49: Company Y Lean Resource Matrix

At lower levels of lean resource mapping it is possible to look in more detail at the relationships between functional activities, plant/product/process groupings and the resources deployed to them. Figure 50 shows a detailed lean resource matrix for the gear cells including details of every functional requirement matched to the resource deployed. For example, the operator maintainer covering a product/process/plant based area incorporating gear cell A soft and A hard performs functional requirements including: hobber setting, shaver setting, deburrer setting, honer setting, grinder setting, gear inline inspection setting, shop floor quality control, 1st line maintenance and finally plant operation.

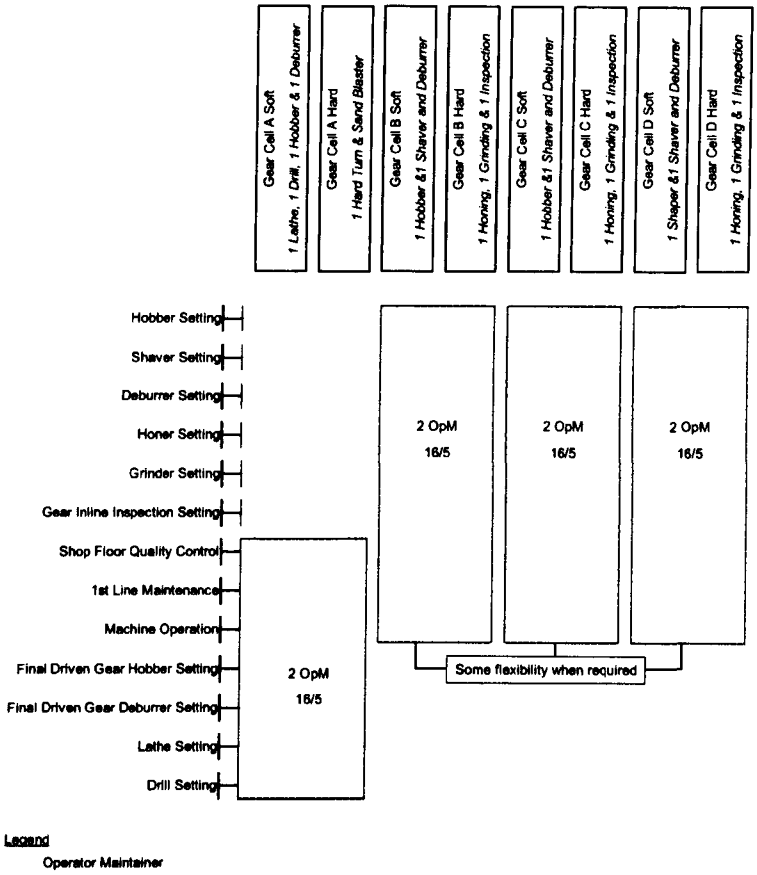

Figure 50: Company Y Gear Cell Lean Resource Matrix

6.5.4 Company X & Y Lean Resource Matrix Analysis

The lean resource framework has been used as a sequential data collection tool building a holistic view of firms' resource deployment through the lens of a lean resource matrix. As an analysis tool the lean resource matrix can be used to identify areas of resource flexibility and any potential disconnectivities between people, plant, processes and products. To investigate this theory in more detail, analysis will be made of the lean resource matrices for Companies X & Y.

Company X Analysis

Referencing the lean resource data collection for Company X, Figure 42 presented the operations level lean resource matrix which will now be analysed in detail looking at how functional requirements (shown vertically) and plant, products and processes (shown horizontally) are resourced. First an evaluation of each of the functional connectivities for inferences of vertical polarisation will be discussed followed by perpendicular evaluation of plant, product and process connectivities for inferences of horizontal polarisation.

Company X Vertical Polarisation

Reviewing each of the functional requirements the 3rd line maintenance is shown at the bottom of the lean resource matrix presented by the Author in Figure 42. Typically 3rd line maintenance involves major engineering project implementation or turnaround maintenance engineering activities, both carried out with the plant offline. In this instance the functional requirement is resourced by either trades people carrying out functional requirements in 1st & 2nd line maintenance activities and specialist contract personnel as required. This indicates a good level of flexibility exists around the 3rd line maintenance function although this could be improved upon by including personnel who operate the plant as they are currently vertically polarised from any 3rd line maintenance activities.

Typically 2nd line maintenance involves routine maintenance engineering functions such as planned preventative maintenance (plant offline) as well as deferred plant repairs and minor project engineering implementation. Similarly to 3rd line maintenance, 2nd line maintenance functional requirements are resourced by trades people performing other functional requirements in 1st and 3rd line maintenance (when required). This indicates a good level of resource flexibility exists around the 2nd line maintenance function although as with the 3rd line maintenance function this could be improved upon by including personnel operating the plant as they are currently vertically polarized from any 2nd line maintenance activities. Also, antithetically, 2nd line maintenance functional resources are vertically polarised from performing any non-maintenance functional activities such as plant setting.

Typically 1st line maintenance involves routine maintenance activities such as planned preventative maintenance (plant online) as well as unplanned maintenance activities such as emergency breakdowns. Similarly to the 2nd & 3rd line maintenance functions 1st line maintenance functional requirements are resourced by trades people performing other functional requirements -when required- in 2nd & 3rd line maintenance. This indicates a good level of resource flexibility exists around the 1st line maintenance function although as with 2nd & 3rd line maintenance activities personnel operating the plant are vertically polarised from any 1st line maintenance activities and antithetically 1st line maintenance resources are vertically polarised from performing any non-maintenance functions.

Expert setting skills typically involve process setting activities such as troubleshooting, new product process variable parameter establishment, process improvement and fine tuning changeovers from one product to another. In this lean resource matrix example there is a mixture of expert setting skills functional resource deployment. For example, the expert setting for spring manufacture is resourced by a multi skilled operator also performing machine operation, shop floor quality control and routine setting skills. Dissimilarly, valve actuator and Ascot injection moulding expert setting skills are resourced by dedicated teams of senior setters. Finally, there are examples of expert setting skill functional requirements that have not been resourced such as in Bikini injection moulding and Reina 49 injection moulding.

Reviewing the multi-skilled approach to performing the expert setting function there is a good level of vertical resource flexibility present. However, the reality of achieving expert setting skills with a machine operator may indicate an imbalance in the dynamic matching of functional resource requirements. Reviewing the valve actuator and Ascot injection moulding approach to resourcing the expert setting skill function shows a very low level of vertical flexibility. This vertical polarisation may indicate skilled personnel are only being fully utilised for a fraction of their available time as expert setting skills polarized in one asset grouping are only adding '*value*' for a fraction of their available time, the time when they are fully using the skills they are paid for.

Routine setting skills are usually based around changing over processes from one product to another ensuring compliance with manufacturing requirements such as product specification and processing efficiency. As with the expert settings skills, there is a dissimilar approach to resource deployment. Again the spring coiling is resourced by a multi-skilled operator performing other functional activities and valve actuator injection moulding is resourced by a dedicated team of routine setters. In this instance the Ascot injection moulding routine setting function has no resource assigned to it suggesting the expert setting resource may be being used to perform routine setting activities. This is an example of bad vertical flexibility, where setters are forced to carry out duties where their skills are not being fully utilised.

The shop floor quality control (QC) function typically involves ensuring products are manufactured to the correct specification. As with the expert and routine setting skills functions, there are dissimilar approaches to the resource deployment of the shop floor quality control function. For example, the spring coiling group resources the QC function with a multi-skilled operator also performing additional functional activities whilst antithetically, the valve actuator and Ascot injection moulding are resourced by a dedicated team of quality controllers. For the raw materials group there is no shop floor quality control resource indicating a lack of goods inward inspection.

Finally, the machine operation function typically involves activities such as loading and unloading of machines and packaging finished products. Similarly to the expert and routine setting and shop floor quality control functions, there are dissimilar approaches to the resource deployment of machine operators. Some operators are vertically polarized and others perform additional functional activities showing good levels of flexibility.

In summary, the lean resource matrix for Company X has shown there is an imbalance in the dynamic matching of resources to functional requirements indicating vertical polarisation exists in some instances.

Company X Horizontal Polarisation

The functional resource deployment has been discussed in isolation and now the perpendicular plant, product and processes horizontal view must be reviewed identifying potential inferences of horizontal polarisation.

The 1st, 2nd & 3rd line maintenance functions are shown horizontally spread covering all process groupings. This indicates a high level of flexibility in matching functional resource requirements with plant, products and processes. However, for 1st line maintenance this may be a good approach to resource deployment but effective 2nd and 3rd line maintenance function requirements require expert process/plant/product group knowledge. For example the mechanical and electrical/electronic design for extrusion and injection moulding machinery are very different. Typically, 2nd line maintenance functional requirements are resourced by asset group technology allowing for a technical focus.

In this example the expert setting skills, routine setting skills, shop floor quality control and machine operation share similar approaches to resource deployment as has been identified in the vertical polarisation analysis. Of the 16 plant, process, product groupings only the valve stem and valve housing injection moulding have shared resources covering these functions. The remaining groups are all horizontally polarised with no shared resources and no indicated flexibility between groups.

Combining the vertical and horizontal polarisation analysis, Company X has examples of resources both vertically and horizontally polarised offering no flexibility between function and product, plant and process grouping. For example, the senior setter function for the valve actuator injection moulding group is both vertically polarised from performing other functions in that grouping and horizontally polarised from resourcing similar functional requirements in other groups. Ideally to fully utilise the senior setting functional resource a horizontal flexibility with similar process, plant and product groupings would be beneficial as is shown for the valve stem and valve housing injection moulding expert setting function.

Company Y Analysis

With reference to the lean resource data collection for Company Y, Figure 49 presented the operations level lean resource matrix and Figure 50 presented a lower level lean resource matrix focusing on the manufacturing gear cells. These matrices will now be analysed in detail identifying inferences of vertical and/or horizontal polarisation.

Company Y Vertical Polarisation

The 3rd line maintenance function shown on the operations level lean resource matrix presents a similar approach to resource deployment as Company X. In this instance the functional requirement is resourced by either trades people carrying out functional requirements in 2nd line maintenance activities and/or specialist contract personnel as required. This indicates a good level of flexibility exists around the 3rd line maintenance function although this could be improved upon by including personnel who operate the plant as they are currently vertically polarised from any 3rd line maintenance activities.

The 2nd line maintenance function shown on the operations level lean resource matrix also presents a similar approach to resource deployment as Company X. In the same way to 3rd line maintenance, 2nd line maintenance functional requirements are resourced by trades people performing other functional requirements in 3rd line maintenance (when required). This indicates a good level or resource flexibility exists around the 2nd line maintenance function although as with the 3rd line maintenance function this could be improved upon by including personnel operating the plant as they are currently vertically polarised from any 2nd line maintenance activities. Also, antithetically, 2nd line maintenance functional resources are vertically polarised from performing any non-maintenance functional activities such as plant setting.

Diametrical to Company X, the operations level lean resource matrix shows a very different approach to resource deployment for 1st line maintenance. In this instance the 1st line maintenance functional requirement is performed by an operator maintainer who also completes other functional responsibilities. This integration of the 1st line maintenance functional activity indicates an adoption of a TPM strategy towards asset management where plant operators have responsibility for the maintenance of the equipment they are working on. However, in this example the 1st line maintenance is shown vertically polarized from the 2nd & 3rd line maintenance functions.

The functional requirements for the operator maintainer are shown in more detail on the lower level lean resource matrix including details of every functional requirement matched to the resource deployed. For example, the operator maintainer covering a product/process/plant based area incorporating gear cell A soft and A hard performs functional requirements including: hobber setting, shaver setting, deburrer setting, honer setting, grinder setting, gear inline inspection setting, shop floor quality control, 1st line maintenance and finally plant operation. This shows a very high level of functional integration which is typically found in lean manufacturing where processes are split by value streams with dedicated plant producing a single product or product grouping[49]. The reality of this functional integration means the operator maintainer has to be very skilful and knowledgeable about each individual process within their manufacturing cell.

[49] The researcher visited the manufacturing plant in Japan where the vehicle manufacturers made exactly the same products as Company Y. Interestingly, the plant, product, process and people resource grouping strategy was very different with the grouping based around processing type rather than product type as has been identified with Company Y. This focus on processing groups meant there was a high level of skill and knowledge in each process but more work-in-progress (WIP) as products were processed in large batches stored between the different process groupings.

Taking into account Company Y had been recently set-up as a new business manufacturing high precision components -the criticality of which meant this was the first time the components had been manufactured outside of Japan- the learning curve for the new maintainer operator would have to be very steep if they were to match the knowledge and skill levels required to achieve the quality and productivity standards expected[50].

Company Y Horizontal Polarisation

Similarly to Company X, the 2nd & 3rd line maintenance functions are shown horizontally spread covering all process groupings. This indicates a high level of flexibility in matching functional resource requirements with plant, products and processes. However, effective 2nd and 3rd line maintenance function requirements require expert process/plant/product group knowledge. For example the mechanical and electrical/electronic design for honing and spline rolling machinery are very different. Typically, 2nd line maintenance functional requirements are resourced by asset group technology allowing for a technical focus and ownership of a particular grouping.

As has been identified in the vertical polarisation analysis Company Y have adopted a product grouping approach to product, process and plant resource deployment. For example, there are eight operator maintainers covering four product based manufacturing cells (one per shift). Cell A soft and hard is shown horizontally polarized from Cells B, C, & D. Cells B, C & D are nearly identical in their processing plant and there is some flexibility shown reducing the level of horizontal polarisation.

However, the problems identified in the vertical polarisation analysis -with many integrated functional requirement- are not helped when matched with the segregation of heterogeneous processes into product based groups. This indicates there must be a balance between vertical flexibility and horizontal polarisation of product based processes typical in lean product based value streams. In this example a more homogenised approach to process resource deployment could achieve the

[50] In reality Company Y employed semi-skilled personnel to fill the position of maintainer operators. The consequence of this was initially a very high level of rejects due to non conformance to specification resulting in 100% inspection being made on all products before shipment to the customer. A buffer stock of finished goods was introduced to ensure delivery to the customer would not be affected by the high level of rejects.

horizontal polarisation required by lean product based value streams using deployed resources splitting functional requirements between the operator maintainers with each specialising in different functional requirements. This suggests by reducing vertical flexibility of functional requirements it is possible to achieve the lean prerequisite of horizontally polarised product based process groups but maintain high levels of horizontal flexibility between functional resources.

6.5.5 Summary

The preceding analysis has identified occurrences of vertical and horizontal polarisation in both Company X and Company Y. Company X -adopting a non lean approach- showed a process based structure with high levels of horizontal polarisation between the process based groups matched with high levels of vertical polarisation through functional disconnectivity. Company Y –adopting a lean approach- showed a product based structure with deliberate horizontal polarisation of a product based heterogeneous process value stream matched with high levels of vertical flexibility through functional integration of resource requirements.

6.6 Discussion

R4. Will a new lean tool introduced as a lean resource mapping framework complement the extant lean conceptual framework through the introduction of an 8^{th} waste classified as polarisation?

Figure 34 showed the lean resource conceptual framework which was operationalised through the identification of an eighth waste classified as polarisation. Identifying instances of polarisation a lean resource mapping framework was also introduced as a useful and practical sequential data gathering methodology compiling information through observation of work practices; one-to-one interviews with employees; group discussions and documentation analysis. Taking a holistic view of the firm, the framework builds toward the development of a lean resource matrix giving a snapshot of resources in relation to the products, processes, plant and people employed.

Complementing the extant lean conceptual framework the lean resource mapping is carried out at the first stage adding an additional step to the five steps to becoming lean proposed by Womack & Jones (1996a; 1996b) now summarised as the 6 steps to becoming lean:

1. *Map resources understanding the relationship between People, Plant, Products & Processes*
2. Specify value
3. Identify the value stream
4. Make the value creating steps flow
5. Promote a "pull" culture
6. Pursue perfection

The eighth waste concept introduced at polarisation is also added to the seven non-value elements in processes as originally specified by Ohno (1988):

1. Overproduction
2. Waiting
3. Transport
4. Inappropriate processing
5. Unnecessary inventory
6. Unnecessary motion
7. Defects
8. *Polarisation of resources*

As well as providing a useful new tool for helping to realise firm competences and capabilities under the RBV of the firm; the adaptation of Kelly's (1988; 2001) maintenance engineering resource structure to view operations has provided a useful multi-level framework for the mapping of resources and levels of flexibility found between people, plant, products and processes. Additionally, the framework provides a mechanism for the strategic planning of resources to gain competitive advantage. Using terms from extant value stream mapping (VSM) literature (Rother and Shook, 1998; Jones and Womack, 2003) the framework provides a '*current state matrix*' and can be used to identify a '*future state matrix/ideal state matrix*' of resources, business capabilities and competences for strategic planning purposes as has been shown in the case examples[51].

[51] The author has also developed a competency matrix to support this development called a '4 in 1, 1 in 4' matrix'. As a tool to support managers of personnel the competency matrix tracks individual activity competency levels vertically and individual resource levels horizontally all matched to targets based around fulfilling the overall process purpose. This is also linked to the lean recruitment framework discussed in the Appendix A.

Building on previous research introducing the Toyota Production System and Lean concept combined with theories taken from economic and strategy literature, a conceptual framework has been introduced defining a useful approach for overcoming the extant criticisms of the lean conceptual framework. Developing the new approach whilst testing its usefulness in an industrial setting, a lean resource mapping framework is introduced offering a completory approach to value stream mapping. The concept of lean is seen as a fundamental requirement to all competitive manufacturers and the proposed framework is introduced as a development toward achieving both economy of scale efficiencies and economy of scope flexibilities realising subsequent competitive advantage.

A Definition of the 8^{th} Waste Polarisation

Polarisation can be defined as a wasted opportunity in resource deployment set against either functional requirements (vertical polarisation) and/or product, process and plant (horizontal polarisation). Instances of joint vertical and horizontal polarisation are the worst form of waste typically isolating a resource to a single functional activity in a single product, plant and process grouping. An example of this was evident in the action case study at Company X where the senior setter function for the valve actuator injection moulding group is shown both vertically polarised from performing other functions in that grouping and horizontally polarised from resourcing similar functional requirements in other groups. Ideally to fully utilise the senior setting functional resource a horizontal flexibility with similar process, plant and product groupings would be beneficial.

Other examples of polarisation occur when there is an imbalance extant between functional requirements and product, process and plant groupings. An example of this is evident in action case study at Company Y where the operator maintainer covering a product/process/plant based area incorporating gear cell A soft and A hard performs functional requirements including: hobber setting, shaver setting, deburrer setting, honer setting, grinder setting, gear inline inspection setting, shop floor quality control, 1^{st} line maintenance and finally plant operation. This shows a very high level of functional integration which is typically found in lean manufacturing where processes are split by value streams with dedicated plant producing a single product or product grouping.

The reality of this functional integration means the operator maintainer has to be very skilful and knowledgeable about each individual process within their manufacturing cell. However, when reviewing the horizontal flexibilities the 8 operator maintainers covering 4 product based manufacturing cells are shown horizontally polarised from each other with the segregation of heterogeneous processes into product based groups presenting a wasted opportunity of resource deployment. This indicates there must be a balance between vertical flexibility and horizontal polarisation of product based processes typical in lean product based value streams.

In this example a more homogenised approach to process resource deployment could achieve the horizontal polarisation required by lean product based value streams using deployed resources splitting functional requirements between the operator maintainers with each specialising in different functional requirements. This suggests by reducing vertical flexibility of functional requirements it is possible to achieve the lean prerequisite of horizontally polarised product based process groups but maintain high levels of horizontal flexibility between functional resources.

6.7 Conclusion

This Chapter has further built on the 5S and OEE concepts introduced in Chapters 4 & 5 validating the concept of an eighth waste and a useful framework for understanding resources and their relationship with plant, products & processes. The next Chapter will discuss how 5S, OEE and the lean resource mapping framework can be combined to develop a value improvement model for repetitive processes.

Chapter 7: A Value Improvement Model for Repetitive Processes: Application to Manufacturing

7.1 Introduction

Building on the individual developments to the six-sigma & lean conceptual frameworks presented in Chapters 3 through to 6, this Chapter brings these individual elements together into a single conceptual framework introduced as a value improvement model for repetitive processes. The value improvement model effectiveness is operationalised and tested within a manufacturing case study.

7.2 Developing a Working Value Improvement Model: 1st Draft

7.2.1 First Model Development Process

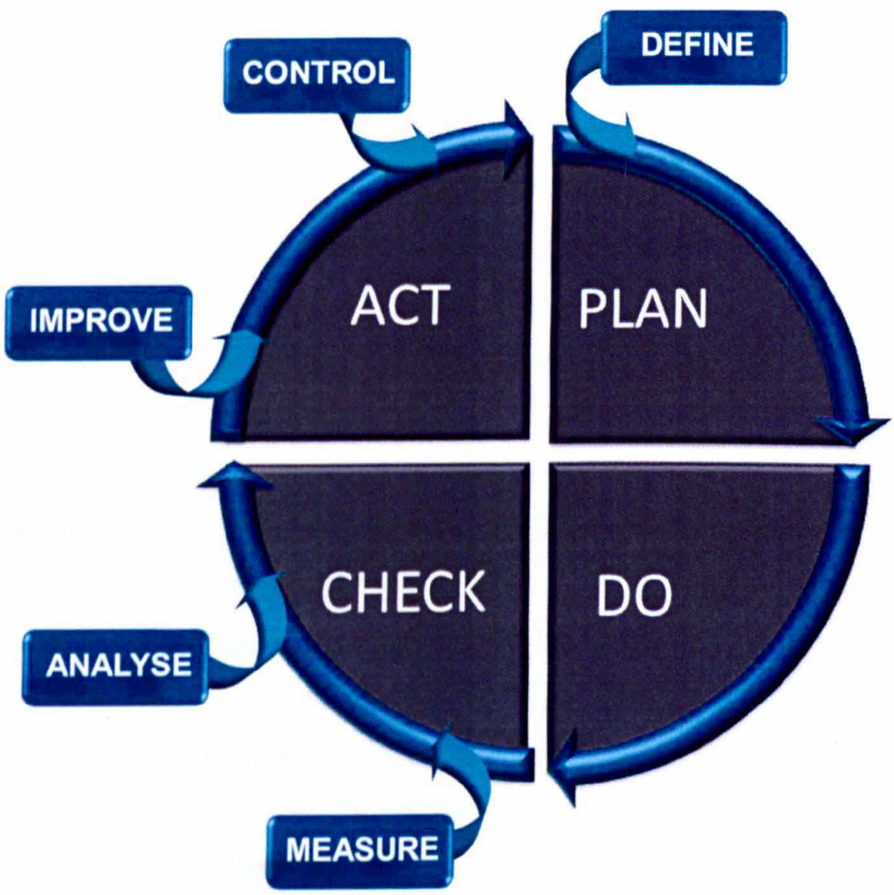

Figure 51: DMAIC & PDCA Knowledge Accumulation Cycle

Developing a value improvement model for repetitive processes, In Figure 51 the Author shows a proposed framework providing a structured approach to sustainable value improvements building on the six-sigma DMAIC and Deming/Shewhart PDCA cycles. Of interest to this discussion is the original

Shewhart Cycle discussed by Deming (1986) where the four step PDCA[52] has a fifth step defined as *"Repeat step 1, with knowledge accumulated"* & a sixth step defined as *"Repeat Step 2, and onward"*.

This continuous knowledge accumulation cycle allows for better understanding of the process to be improved rather than being a one off improvement typically found in the linear and sequential six-sigma DMAIC improvement process. Figure 51 shows how the PDCA and DMAIC improvement can be structured to complement each other. DMAIC is added to the continuous cycle of PDCA and the PDCA cycle is enhanced by the framework provided by DMAIC.

The proposed value improvement cycle takes the following steps based around seven Ps[53]: Purpose, Perspective, People, Plant, Product, Performance and Process: -

1. Define: Understand what the **Purpose** of the investigation is from the Business' **Perspective**. Quantify the change required perhaps using the six-sigma project charter approach.
2. Plan: Understand how the resource bundles of **People** and **Plant** are aligned to deliver the customer needs detailed in the **Product** description?
3. Do: Run the repetitive **Process** to deliver the **Product**.
4. Check/Measure: Understand the outcomes of the repetitive **Process** and measure **Performance**.
5. Analyse: Analyse the **Performance** comparing the actual outcomes against those specified by the **Product** quantifying examples of waste (lean) and process variability (six-sigma) against the customer **Perspective (Product)** and business **Perspective (Purpose)**.
6. Improve/Act: Change the **Process** inputs based on the outcome analysis.

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[52] Deming also uses Plan→Do→Study→Act where Study is literally looking to understand what can be learnt from the cycle and more importantly what can be predicted in future cycles.

[53] People, Plant, Product & Process are the 4Ps commonly used in manufacturing as a useful framework for understanding problems. There are many different versions of the 4Ps in the literature, for example Liker (2004) proposes the 4 P model is based around: Philosophy, Process, People/Partners and Problem Solving.

7. Control: Put in place control mechanisms to ensure the **Process** changes are sustained.
8. Define 2: Start again revisiting the **Purpose & Perspective**.

Also supporting the value improvement model framework is the systems thinking approach to describing a process by answering the following questions, 'who', 'what', 'why', 'where, 'when' and 'how' (Godfrey, 2010). Developing this systems approach further, Blockley (2010) suggests all processes have attributes that are characterised by understanding the relations between these questions:

Why? = How? (What?, Who?, Where? & When?)

Building on the link with DMAIC and PDCA presented in Figure 51 and the eight steps of the proposed value improvement cycle, in Figure 52 the Author presents an initial conceptual model useful for visualising the cycle. Reviewing the PDCA inputs to the model, the repetitive cycle is placed under Deming's 'Do' with inputs of People, Plant & Products under 'Plan'.

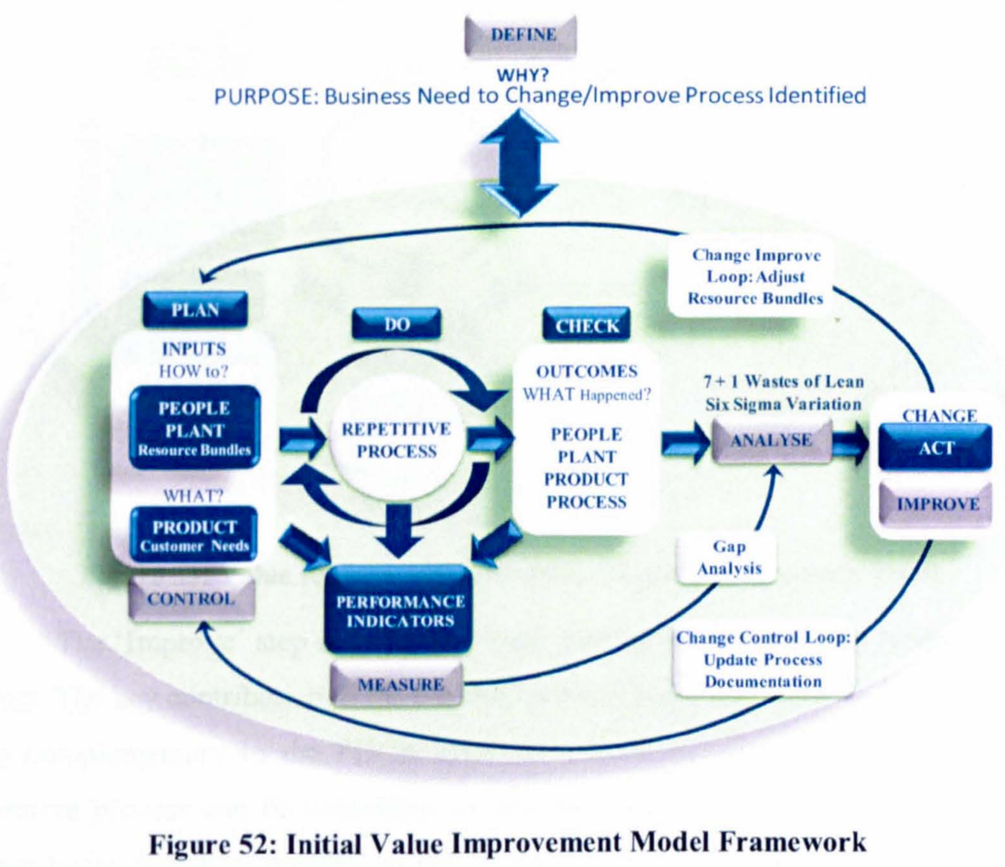

Figure 52: Initial Value Improvement Model Framework

The outcomes of the repetitive process are shown under 'Check' with particular performance indicators used to facilitate the identification of gaps to the customer needs (Product). Finally the 'Act' is the point of change where the inputs to the repetitive process are adjusted in a change, improve loop and the repetitive cycle can be completed again.

Complementing Deming's PDCA are the five steps of the six-sigma DMAIC process. The first step 'Define' is shown sitting outside of the repetitive process[54] and is based around the purpose for the intervention or understanding of the repetitive process in question from a business perspective. Following the Plan, Do & Check stages is the 'Measure' step and measurement of a relevant performance indicator to understand how the process has performed so that the 'Analyse' step can be completed understanding the gap between the customer and business requirements using waste and variation analysis tools for the lean and six-sigma toolkits.

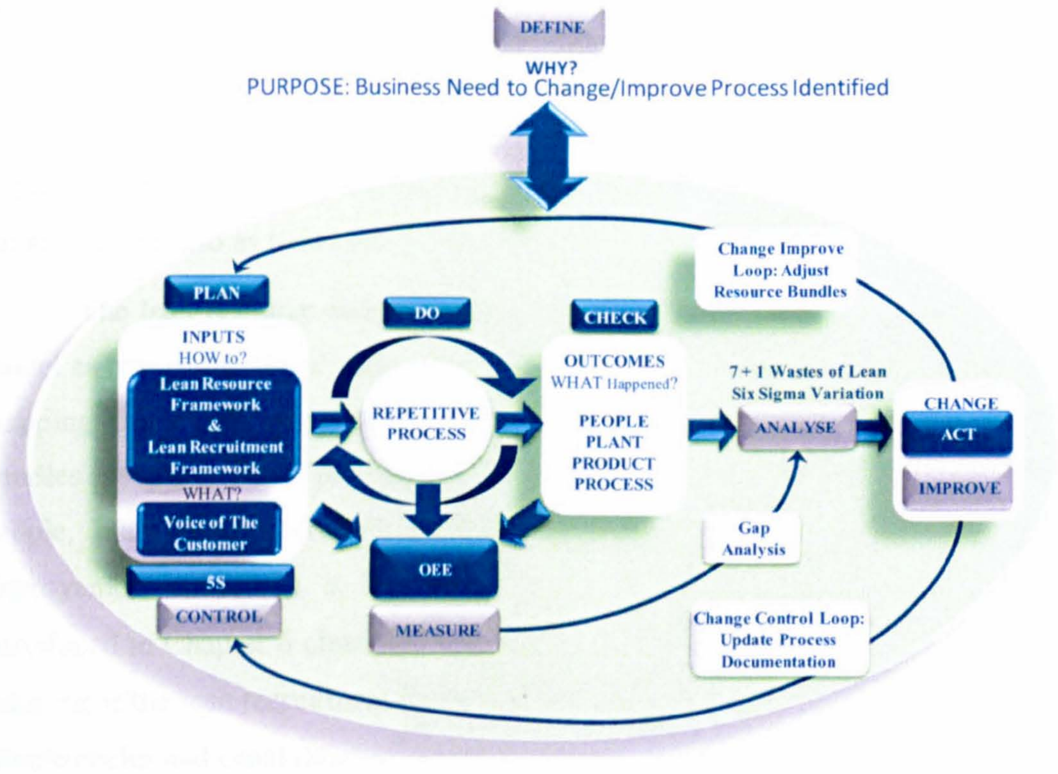

Figure 53: Value Improvement Model for Repetitive Processes Draft

The 'Improve' step matches the 'Act' step and makes changes to the process inputs. The key contribution to the DMAIC process is the final step 'Control'. This is also complementary to the PDCA cycle as it is at this point the changes to the repetitive process can be controlled so that any changes made are robust and the inputs to the repetitive process do not go back to the format before the change was made.

[54] The green oval shape represents the internal environment of the repetitive process.

Linking the preceding work presented in this thesis with the initial value improvement framework presented in Figure 52, in Figure 53 the Author introduces the 1st working draft of a conceptual framework in the development of a value improvement model for repetitive processes including the placement of the individual concepts of: 5S, OEE, Lean Resource Framework and finally the Lean Recruitment Framework (Appendix A).

5S has been added to the model directly above the 'Control' stage and as has been argued already in Chapter 4, the philosophy of 5S is seen as the platform to build any improvements upon, especially those direct inputs providing a service to the repetitive process. For the Value Improvement Model this is a critical element to both understanding the process and managing the direct process inputs themselves[55].

OEE has been added to the model as part of the 'Measure' stage and is shown as linked to the direct process inputs, repetitive process and outcomes. As has been argued in Chapter 5, OEE can be used to provide an indication of lean six-sigma capability and also as a measure in the DMAIC process.

The lean resource and lean recruitment frameworks have been added to the model as part of the 'Plan' stage. As has been argued in Chapter 6, the lean resource mapping framework provides a useful tool for understanding how the resource bundles (people & plant) provide a service to the repetitive process. The matching of people, plant and process is a key element in the development of a value improvement model as is the identification of instances of the eighth waste introduced in Chapter 6 classified as polarisation. Complementing the lean resource mapping is the lean recruitment framework which can be used to understand the core competencies and capabilities of the people element of the repetitive process.

The internal elements on the value improvement model focus on measuring/analysing an outcome based on a requirement and feeding back improvements and updating process controls. This could be classified as hard systems thinking (Checkland, 1981) which was developed to solve real-world problems during and after the Second World War. Although proven to be very useful, hard systems thinking has received considerable criticism focusing on its

[55] The importance of this will be developed in the next sections where multiple case studies will show the influence 5S (as a philosophy) can have over a repetitive process.

limitations when understanding complexity, politics, plurality, beliefs and values (Jackson, 2003). Looking to overcome these potential weaknesses the value improvement model also takes into account internal and external influencing factors taking a more holistic approach encompassing elements of soft systems thinking as introduced by Checkland (1981). This understanding of the internal and external influencing factors of a repetitive process as well as the 'given' direct inputs is seen as the key to successful business change and therefore supports the realisation of sustainable competitive advantage.

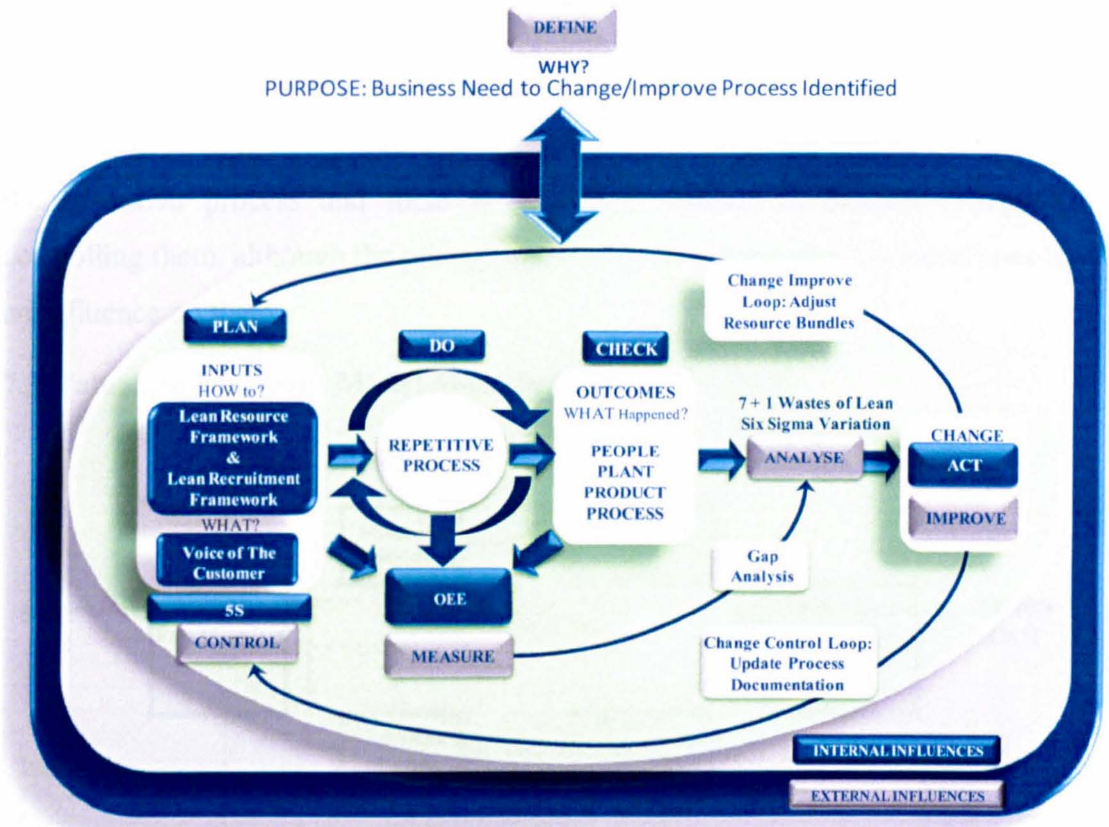

Figure 54: Value Improvement Model for Repetitive Processes 1st Draft

Building a new approach to using lean and six-sigma tools through the development of a value improvement model for repetitive processes and overcoming the criticisms of lean and six-sigma implementations where improvements are made in isolation without a full understanding of other processes, people and plant (McAdam and Lafferty, 2004; Nonthaleerak and Hendry, 2008; Näslund, 2008), the Author presents Figure 54 showing the value improvement model presented in Figure 53 with two additional bands around the outside.

The first band -shown overlapping with the repetitive process- represents the internal influencing factors to the particular repetitive process. These influencing factors are the things which do not directly influence the process but have either a positive or negative impact on the repetitive process. For example, other processes linked to the repetitive process must be understood and these would be included in the internal influencing factors. The internal influences area also contains those indirect elements which are more generic to the business environment such as culture, leadership, business strategy, core competencies and are process inputs which can be changed and controlled but not as easily as the direct inputs.

The outer band represents the external environment influencing factors which similarly to the internal influencing factors can be either positive or negative. Examples of external influencing factors include legislation, climate (both business and weather) and industry regulations. The external factors are outside the control of the repetitive process and there is very little chance of directly changing or controlling them, although the process is influenced by them and can sometimes have an influence on them.

7.3 Value Improvement Model Manufacturing Case Study

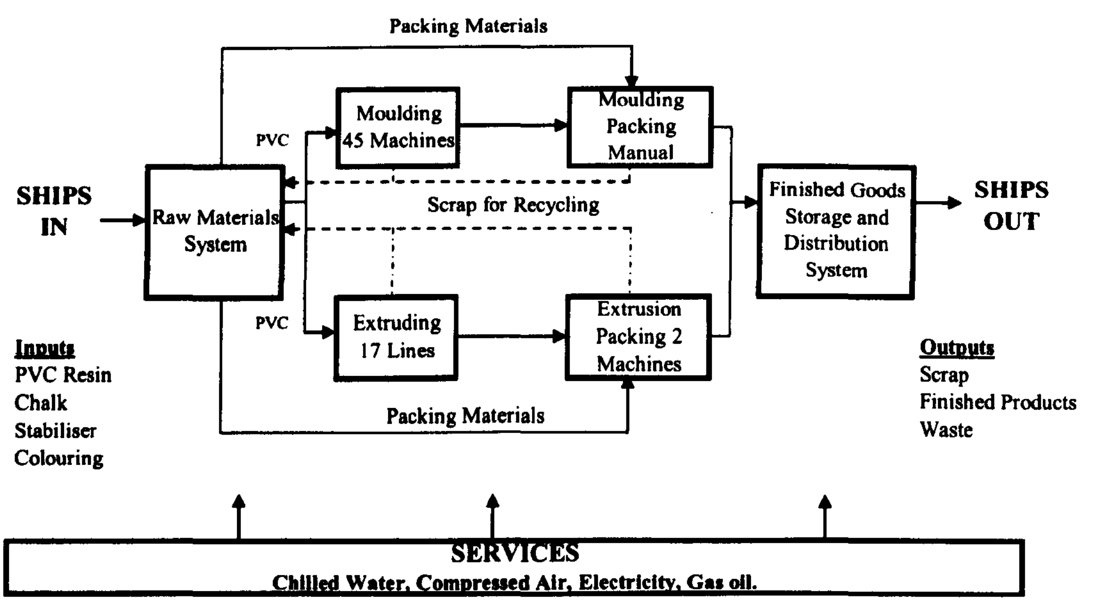

Figure 55: Process Flow Diagram

Operationalising the value improvement conceptual framework and testing the usefulness as a practitioner tool, the model presented in Figure 54 will be used on the case study example presented in Chapter 5 developing a value improvement model for the plastic pipe, extrusion manufacturing process. The case study was made at a large sized UK manufacturing company producing plastic plumbing and drainage products for both retail and construction civil engineering marketplaces.

Figure 55 shows a simplified process flow diagram for the manufacturing operations used within the Company. The two main production processes employed utilise extruding and injection moulding technologies, with all PVC[56] blended on site from raw materials.

A management review of existing key performance indicators (KPIs) identified current scrap levels in manufacturing were averaging above 12% and in the last financial year this was estimated to have cost the business £1.4 million in replacement materials alone equating to over £7.6 million over the last 5 years (using available data). Further analysis identified one particular process (Orion[57]) had accounted for 15% of the total scrap generated during the last financial year. An improvement project was established to identify the root cause of this problem and to put in place sustainable improvements at minimal total cost.

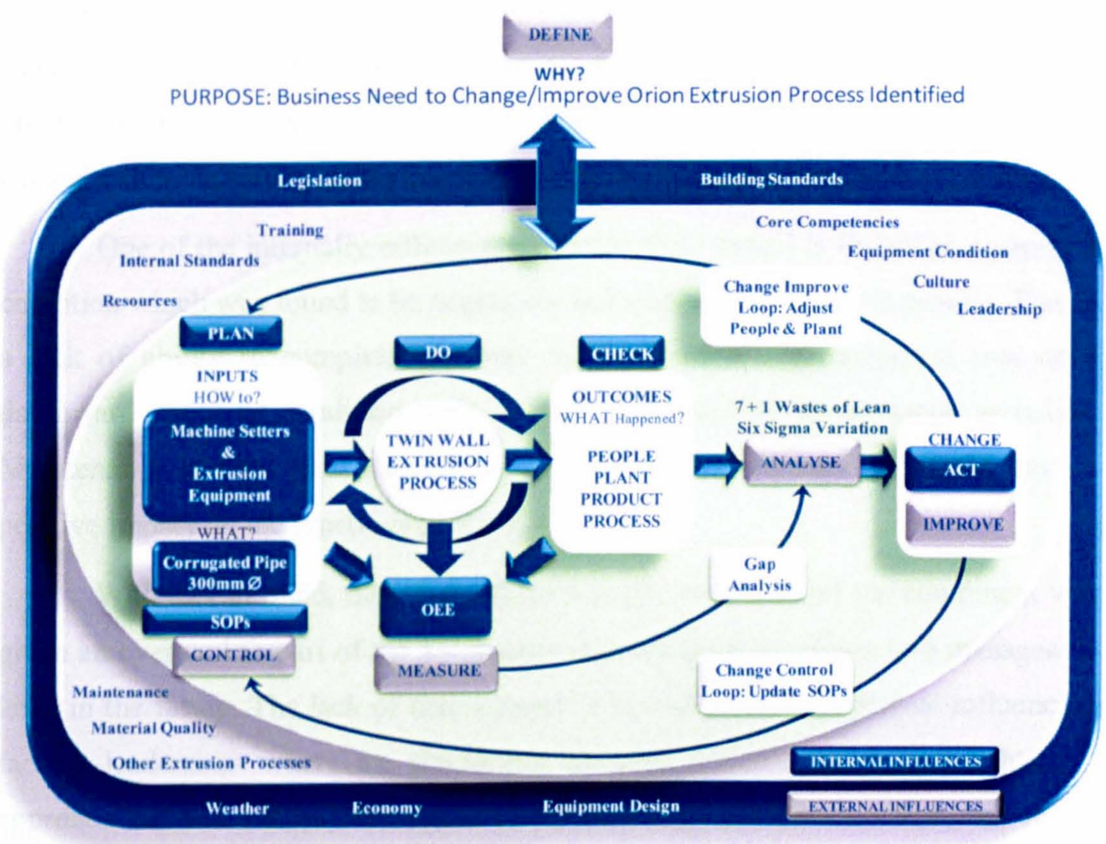

Figure 56: Value Improvement Model for Manufacturing Process

[56] PVC is short for polyvinyl chloride which is a commonly used plastic material in plumbing and drainage products in particular the guttering and pipe systems seen outside houses and buildings.
[57] The process name is a pseudonym and the Company name is not mentioned at the request of the Managing Director whose permission was obtained for using the data in the case study.

In Figure 56 the Author shows the value improvement model developed for the Orion extrusion repetitive process including the internal and external influencing factors. The resource bundles are represented by the Machine Setters and Extrusion Equipment and the Product is defined as a 300mm diameter corrugated pipe. As discussed in Chapter 5, OEE was used to capture more specific and objective data onto the Orion process and data was collected in collaboration with the process operators, over an initial six-week period.

Utilising the Lean Six-Sigma DMAIC approach, the data collected was analysed and as discussed in Chapter 5 the initial emphasis was made on improving the quality failure modes based around standardising and simplifying the activities carried by the process setters and operators. Following a Kaizen (Imai, 1986; 1997) improvement activity, data was collected for a further 6 week period and analysis demonstrated a significant improvement with the OEE rising from 34% to 62% (see Figure 23: OEE Results after Improvement). This first pass improvement was made on the basis of applying 5S principles to the equipment hardware and for standardising the setting duties developing standard operating procedures (SOPs).

One of the internally influencing factors of the model is shown as equipment condition which was found to be negatively influencing the repetitive process. Due to a lack of ability to complete customer orders on time the equipment was on a downward spiral of condition with no time allocated for maintenance activities. Maintenance is also shown as an internal influencing factor and should have a positive impact on the repetitive process.

With this in mind, during the Kaizen improvement event the equipment was given an overhaul as part of the 5S process improving the condition to a manageable level in the future. The lack of maintenance is linked to another internal influencing factor –leadership- where the production manager had adopted a 'fire-fighting'[58] approach and was running the whole of the extrusion department with a very short-term approach negatively influencing the repetitive process.

Although the improvements to the OEE for the Orion process were significant, an OEE of 62% is a long way from the World Class levels of 85%

[58] Fire-fighting is a term used in industry to classify a management approach based around short-term thinking often ignoring longer-term consequences of decisions made.

suggested by Robinson & Ginder (1995). Therefore looking to further improve the Orion process the OEE data must be further analysed to identify opportunities for improvement. In Figure 57 the Author shows the failure modes presented in order of magnitude. Added to the Pareto graph is a cumulative percentage line facilitating the inclusion of an 80% failure mode block to identify where the focus of improvement should be made.

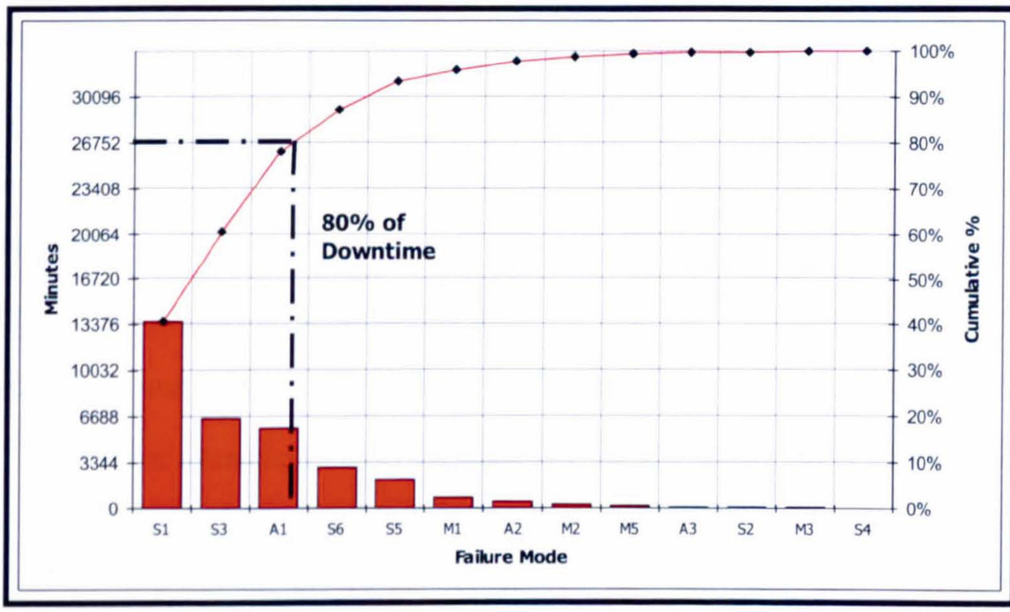

Figure 57: OEE Data Availability Failure Mode Pareto Analysis

Inside the 80% cumulative block of failure mode minutes are 3 of the failure mode categories accounting for nearly 20% of the total failure mode categories and >26 000 minutes of downtime. Of these failure modes two non-related categories account for 38%, S3 (die strip and clean) -which has been improved upon as part of the standardisation and simplification activities discussed in Chapter 5- and A1 (no programme).

More importantly, and responsible for 40% of downtime within the availability element of the OEE calculation, failure mode S1 (waiting setter) represents 25% of the total inefficiencies witnessed within the Orion process. Therefore the focus of the investigation is to identify the root causes for the 40% downtime *waiting setter*[59].

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[59] The term 'setter' refers to a skilled production technician capable of preparing a process for production.

7.3.1 Problem Root-Cause Analysis

Imai (1997) suggests that a problem solving technique known as the '*5 whys?*' can help identify the real root cause of the problem. This technique is applied to the unavailability inefficiency identified: 'waiting setter': -

Problem statement: Over a period of six weeks the Orion process was unavailable for production for 25% of the time.

Why 1?

Q1. Why was the Orion process unavailable for 25% of the time?

A1. There was no setter available to attend the process.

Why 2?

Q2. Why was there no setter available?

A2. There was no setter available for the following reasons[60]:-

- Setter attending to other production processes within the factory due to the absence of other setters (planned and unplanned).
- Setter driving forklift for extrusion department due to absence of usual driver (unplanned).
- Orion process setter off sick or on holiday. No relief cover planned using other Orion setters and no other non-Orion setters capable of setting process.

Why 3?

Q3. Why was the setter attending other processes within the factory?

A3. There is a lack of skilled setters for some of the more complex processes (especially Orion) combined with limited flexibility and an imbalance of setter skills between products. When absences (planned and unplanned) occur production management prioritise setter deployment on a fire-fighting basis.

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[60] At this point the investigation could be broken off into three separate streams to identify the root causes of each of the reasons listed. For brevity, only the first bullet point investigation will be presented. However, the full investigation identified a root cause linking all three of the reasons presented.

Why 4?

Q4. Why is there both a lack of skilled setters and low level of flexibility between product processes?

A4. The production strategy deployed focuses on achieving higher efficiencies delivered through economies of scale using dedicated personal specialising in individual product process setting skills. Complementing the lack of available setters is a zero overtime policy implemented as a result of a flexible working initiative. Poor management of the flexible working agreement means that when setters are absent no arrangements are made to cover their dedicated product process.

From the 5why analysis, the root cause of the waiting setter problem is identified as a consequence of a business strategy focused on delivering economy of scale efficiencies utilising inflexible processes and personnel combined with an imbalance of setter skills. Complementing the rigid production strategy is a human resources strategy incorporating a zero-overtime policy as a result of a flexible working initiative.

In summary, the combination of an inflexible product/process skill base, general disparity of skills and a zero-overtime policy are seen as the cause of the waiting setter effect. Consequently, production managers are forced to fire-fight to meet customer deliveries using whatever resources are available.

7.3.2 Lean Resource Mapping Framework Application

Looking to overcome the problem with resource alignment to fulfil customer expectations through manufacture and delivery of products in a timely manner, the lean resource mapping framework introduced in Chapter 6 is used to understand how the resources (people & plant) are aligned to the products and process. Figure 58 is presented by the author as the operational level resource matrix for the main processes and functional activities used within the Company.

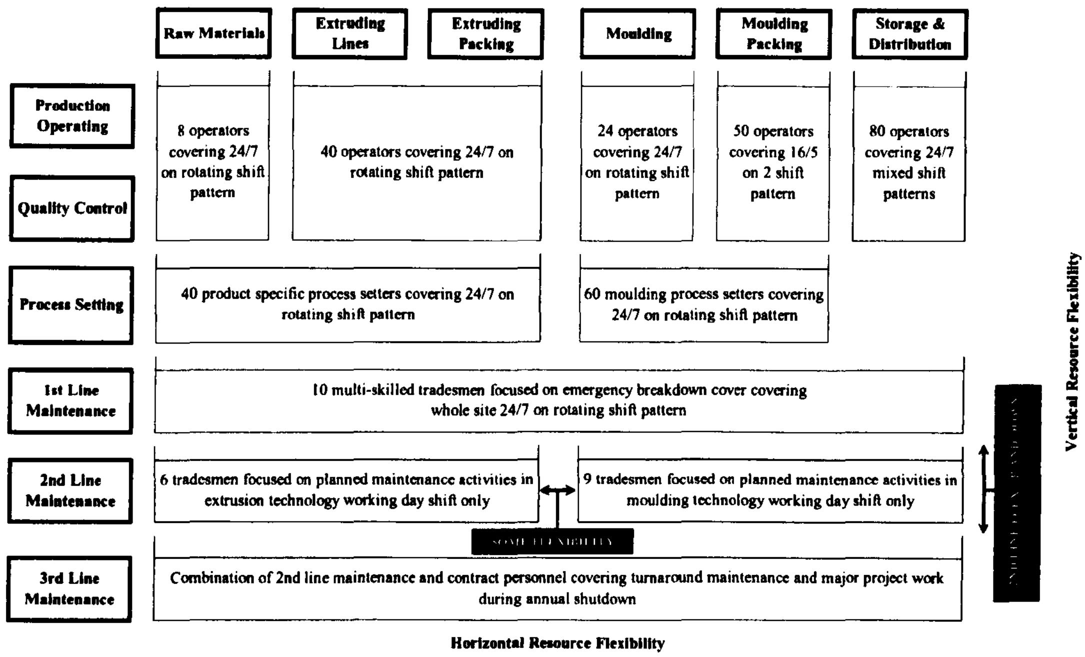

Figure 58: Operational Level Resource Matrix

Reviewing the operational level resource matrix it is possible to see the relationships between processes (shown horizontally) and functional activities (shown vertically). For example, the maintenance function is vertically polarised to the process setting, quality control and production operating functions. In contrast, the quality control function is integrated with production operating. Also showing vertical flexibility, the maintenance function is split into its three main levels[61] and shows how the 2nd line resources are flexible both up and down to cover 1st line and 3rd line maintenance activities[62].

Reviewing the horizontal flexibility it can be seen that the 1st line maintenance resources are covering the whole factory utilising a 24/7 rotating shift pattern. The 2nd line maintenance resources are split between the two main processes, extruding and moulding as are the process setters. Additionally, the 2nd line maintenance resources show some flexibility horizontally between the two main processes.

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[61] The maintenance function is usually split into 3 categories: 1st line maintenance covers corrective repairs and minor preventative online; 2nd line maintenance covers planned preventative, on or off line; and 3rd line maintenance covers major modifications offline (Kelly, 2001).

[62] In an organisation practicing Total Productive Maintenance (TPM) you would expect to see 1st line maintenance activities, and some 2nd line activities, covered by maintainer/operators.

To understand the problems identified within the Orion process the resource diagram must be taken to a lower level of functionality. In Figure 59 the Author shows the current state resource matrix for the extrusion department with the five main product groups utilising extrusion processing techniques spread horizontally. Perpendicular to the product groups are the four levels of setter skills with the Grade 3 setters being the most skilled and experienced and the trainee setters being the least experienced.

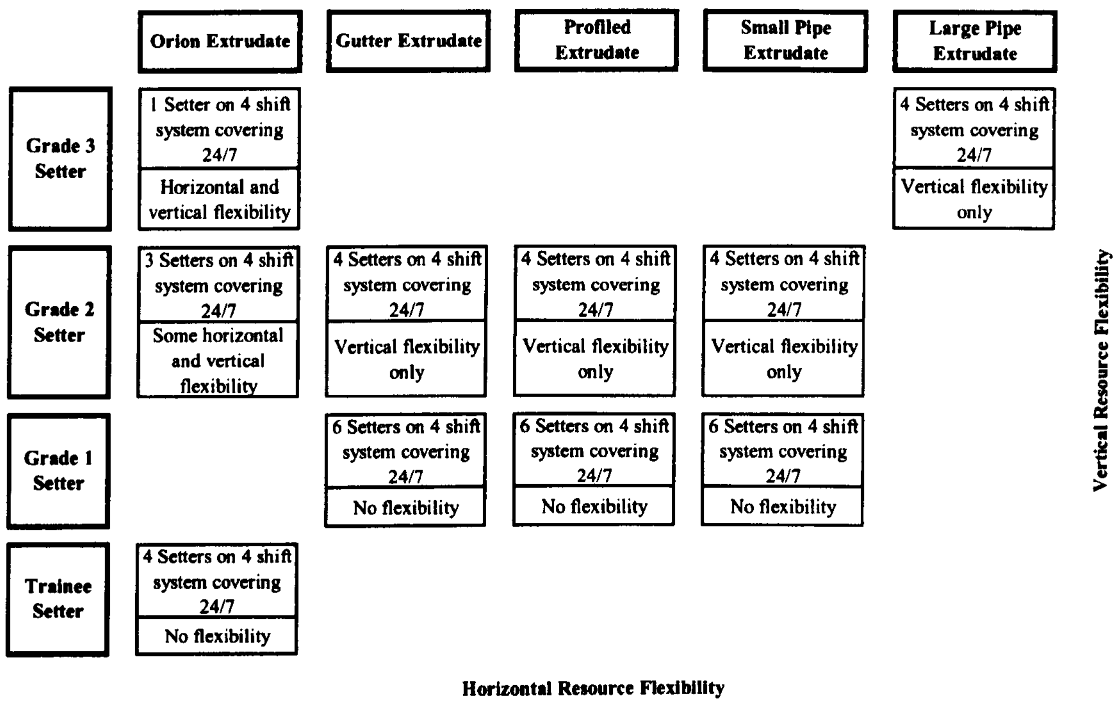

Figure 59: Current State Resource Matrix

Reviewing the resources allocated to the Orion product group it can be seen that there is only one grade 3 setter covering this area. As indicated, this one setter is also horizontally flexible covering all product ranges and vertically flexible covering lower level setter duties. This shows that of the 4 shift crews covering the Orion processes there is only one setter capable of performing the 'expert' troubleshooting and process setting duties on this product specific process line. Consequently, in the absence of a grade 3 setter on their shift, the three, grade 2 Orion setters are forced to be vertically flexible carrying out expert duties they are not capable of doing.

Another observation of the grade 3 setter horizontal plane is that within the large pipe product group there are four grade 3 setters who are horizontally polarised but flexible covering lower level duties. This means that highly skilled setters are carrying out duties that could be quite easily covered by lower level setters when they could be horizontally flexible using their expert setting skills to support other processes.

Overall there seems to be an imbalance in the dynamic matching of the workload between setters and product groups within the extrusion department. For example, there are cases of bad vertical flexibility, where setters are forced to carry out duties which they are either not qualified to do or too qualified to be doing. There is little horizontal flexibility between product groups and the few instances where it exists leave the setter stretched and the department vulnerable to problems (as has been identified in the problem solving 5 why root-cause analysis).

To overcome the imbalance of setter skills and product processing requirements a change in the resource structure must be made. In Figure 60 the Author presents a future state resource matrix taking into account the problems identified through the current state resource matrix.

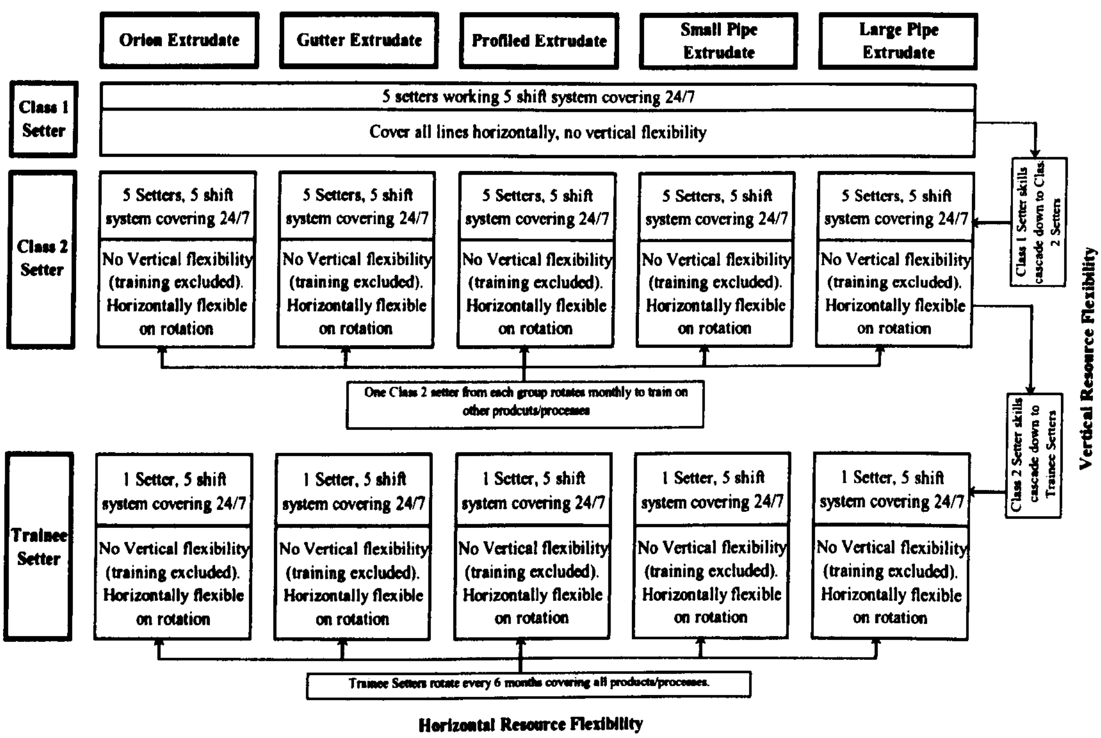

Figure 60: Future State Resource Matrix

Maximising appropriate flexibilities horizontally and vertically, the future state resource matrix is based on a workload incorporating three levels of setter functionability utilising a new 5 shift system to ensure there is always cover where required[63]. For example, the class 1 setter function is covered by five setters with one setter always on duty. The class 1 setters are horizontally flexible focused on utilising their high levels of skill and experience in all product groups with no vertical flexibility.

Reviewing the class 2 setters it can be seen that these are semi-permanently fixed horizontally to product groups with one setter in each group rotating monthly to gain the skills and knowledge to work within other product groups. The class 2 setters are only vertically flexible when being trained by the class 1 setters whose knowledge cascades down to them through fixed training plans with the objective of developing future class 1 setters[64].

Finally, there is one trainee setter in each product group who is fixed horizontally for six months before rotating with all other trainee setters to move into another product group. As with class 2 setters, trainee setters are only vertically flexible when being trained, this time by the class 2 setters who cascade their knowledge down through fixed training plans with the objective of developing future class 2 setters.

7.3.3 Implementing the Lean Resource Matrix

Jones and Womack (2003) argue the realization of a future state map in one big leap is not ideal and therefore suggest the use of an ideal state map as the end goal utilising future state maps as incremental leaps. The development of the ideal state map can be broken down into manageable steps employing yearly value stream plans (Jones and Womack, 2003) incorporating manageable segments of future state maps known as loops (Rother and Shook, 1998).

Applying the VSM implementation techniques to the proposed framework seems logical and applicable. The future state resource matrix would become the ideal state resource matrix and an implementation plan using new future state

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[63] The Company had previously operated a four shift system covering manufacturing operations, day and night, 24 hours a day, seven days a week. The proposed 5 shift system uses an extra shift incorporating redundancy to utilise flexible working agreements.

[64] The lean resource matrix can also be used for succession planning also providing 'stand-by' redundancy in resource utilisation in case of an emergency or change to the system. This perhaps helps to overcome one of the criticisms of lean where resources are kept to a minimum leaving the overall system vulnerable. This also helps overcome one of the other criticisms of lean where flexibility is removed through waste elimination and a linear focus on process optimisation.

resource matrixes and loops as stepping stones (Wernerfelt, 1984) could be developed.

Facilitating the development of personnel, the lean recruitment framework introduced in Appendix A could also be used to match the requirements of the different setter roles assessing the levels of the existing employees and developing training plans to fill any gaps.

7.4 Discussion

R5. Can the DMAIC, 5S, OEE, lean resource mapping framework and the lean recruitment framework tools be incorporated into the development of a single value improvement model for repetitive processes in manufacturing?

The value improvement model has been developed from the individual elements of research presented in Chapters 3-6 and a 1st draft conceptual model has been presented in Figure 54. Operationalising and testing the usefulness of the value improvement model, a case study example was presented and a value improvement model was developed for a manufacturing extrusion repetitive process as shown in Figure 56.

A first pass improvement to the extrusion process applied the 5S principles to standardise the repetitive process which in itself improved the OEE level from 34% to 62%. Looking to further improve the OEE level a review of the value improvement model identified how other processes were influencing the machine Setter availability.

Figure 61 shows the Author's (de-)value improvement model for the extrusion manufacturing process overlaid with the following comments:

- Other external extrusion processes are shown negatively influencing the machine setter availability.
- A consequence of this negative influence is a reduction in the OEE as the extrusion equipment is not operated when the Setters are not available.
- A consequence of the reduced OEE leads to the Leadership fire-fighting to match customer orders.
- A consequence of the fire-fighting leads to a reduction in planned maintenance as the extrusion equipment is not released from production.

- A consequence of the deterioration of the extrusion equipment leads to a reduction in the level of OEE as the availability efficiency element also reduces in parallel to the equipment condition.
- A consequence of this a 'de-value' cycle starts where the leadership continues to fire-fight and the equipment continues to deteriorate until a catastrophic failure causes a major intervention.

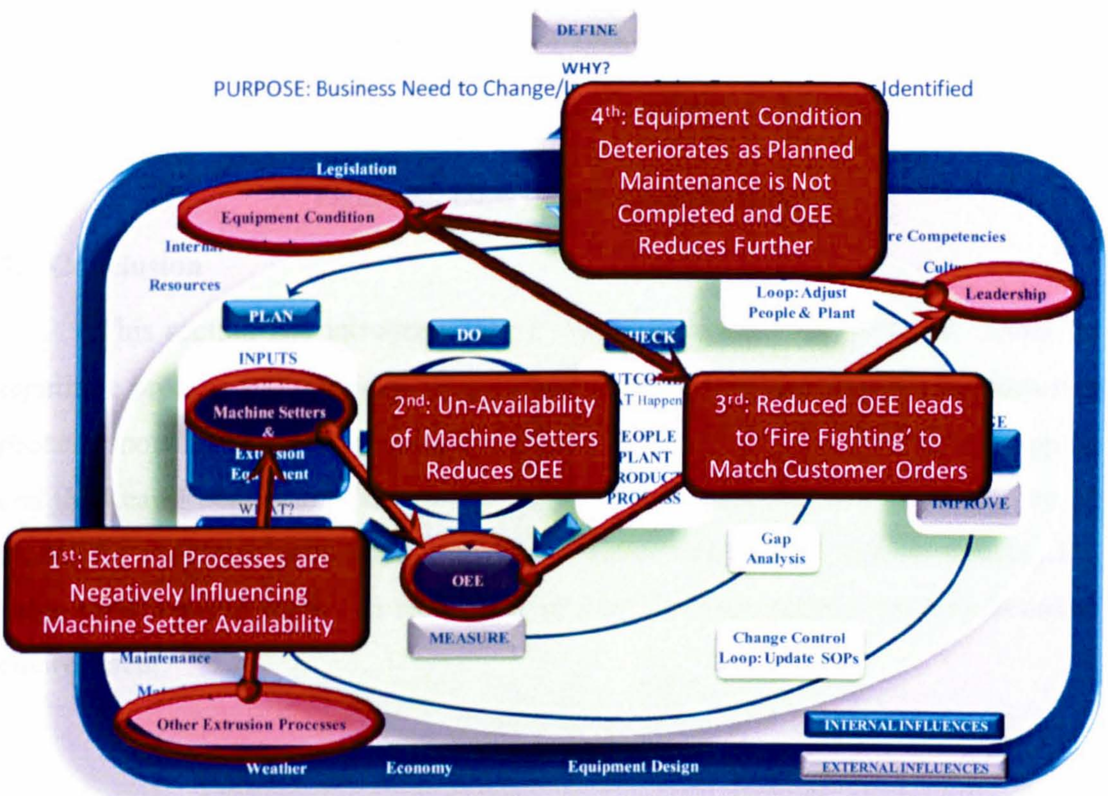

Figure 61: Manufacturing De-Value Improvement Model

Overcoming the problems identified with the external extrusion processes influencing the setter availability, the lean resource mapping framework was applied taking into account the requirements of other processes. Operationalising the proposed resource alignment, the lean recruitment framework was also proposed as a means to evaluate the competency levels of the machine Setters, developing training plans to achieve the required levels of resource flexibility. The results of the manufacturing value improvement are summarised by the Author in Figure 62.

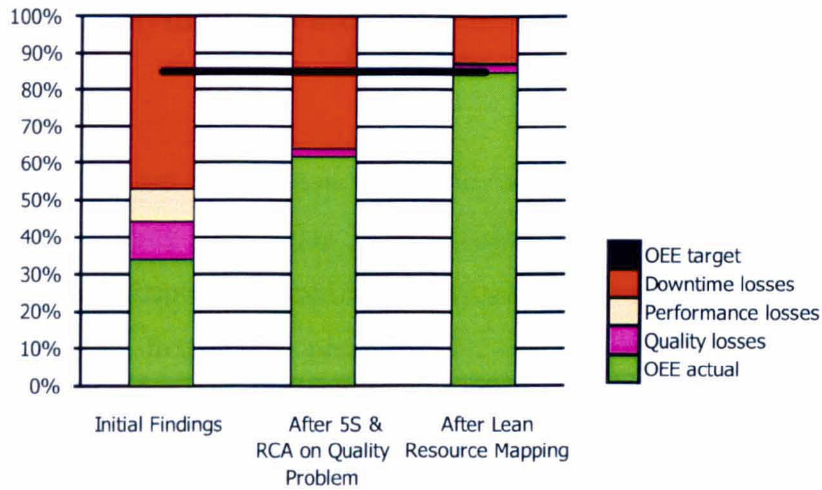

Figure 62: OEE Improvement Results

7.5 Conclusion

This section has introduced the 1st draft of a value improvement model for repetitive process and provided a case study example based around a manufacturing process showing how the individual concepts of 5S, OEE, Lean Resource Mapping and the Lean Recruitment Framework can be incorporated into a value improvement model for repetitive processes. The next Chapter will look to further develop the value improvement model so that it can be used within a service industry business environment.

Chapter 8: Applying the Value Improvement Model to the Service Industry

8.1 Introduction

This next section of the thesis will build on the conceptual framework further testing and developing the value improvement model in a service industry environment. This Chapter is based upon two peer reviewed papers (double blind reviewed) with the first paper presented at, and published in the conference proceedings for 1st UK International Council of Systems Engineering (INCOSE) Conference in November 2010 (Gibbons, 2010b). The second paper has been presented at, and published in the conference proceedings for the Ninth Annual International Conference on Systems Engineering Research (CSER) held in April 2011 (Gibbons, 2011). Both papers build upon the work developed around using the value improvement model in the Airport security process.

8.2 Value Improvement Model Airport Security Process Case Study

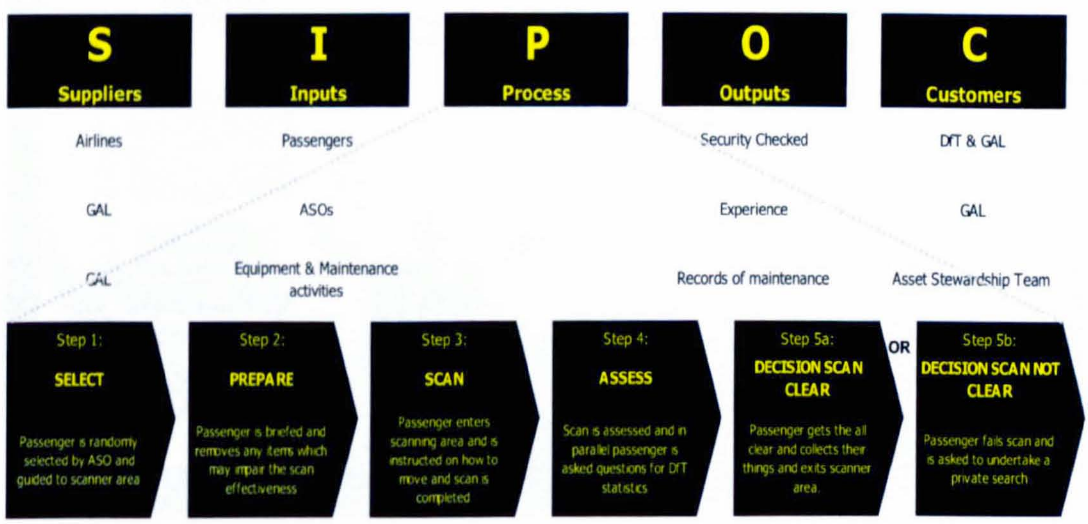

Figure 63: Body Scanner SIPOC

The following case study is based on the full-body scanner process within the overall security screening process of a busy International Airport. Figure 63 illustrates the Author's SIPOC model for the body scanner repetitive process setting the scope of the value improvement model repetitive process application. The SIPOC also gives an overview of the process as well as identifying the key customers receiving an output of the process from the various suppliers of process inputs.

For example, the main supplier to this process is the airlines whose input is the passengers to the: Select→Prepare→Scan→Assess→Scan Clear/Not Clear repetitive process. The output of this process is a security checked passenger on behalf of the customers which are the Airport (Operational & Engineering) and the Department for Transport (DfT).

With the information from the SIPOC model, one-to-one and group discussions and observations of the process it is possible to develop a working value improvement model which can be updated as the improvement process gathers data. Figure 64 shows the Author's value improvement model for the body scanner repetitive process developed from the 1st draft model presented in Figure 54.

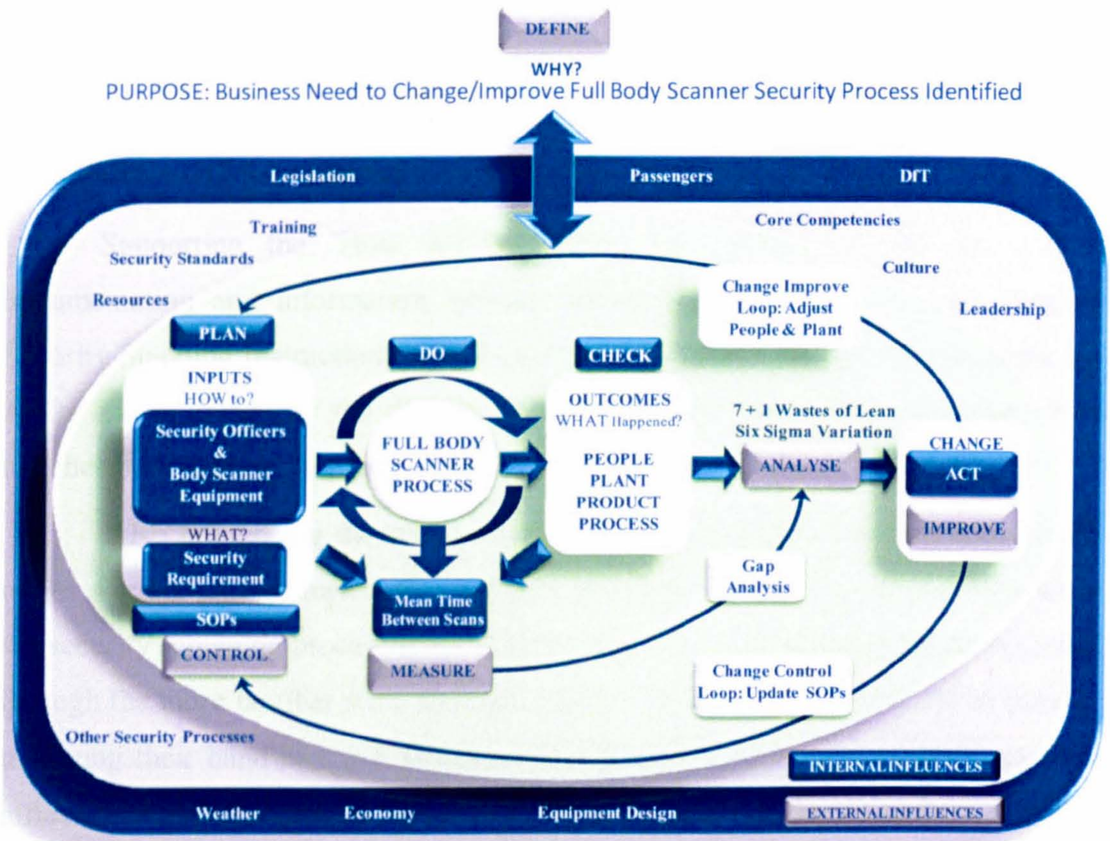

Figure 64: Value Improvement Model for a Body Scanner Process

Developing the body scanner value improvement model, the generic sections have been changed to reflect the specific inputs, measures, outputs and internal and external influencing factors. Starting with the 'why?' and purpose for the improvement cycle, the justification for the body scanner improvement comes from the need to establish a stable and predictable process without compromising security effectiveness. As the body scanner is new technology and could be possibly rolled out as a standard process across the Airport the value improvement model 'Why?' is therefore to establish a stable process without compromising security integrity informing future capacity and security capability requirements.

The planned inputs to the repetitive process focus on identifying the 'How to?' and the 'What is?' elements which are supported by controlling elements which help standardise these process inputs. Developing an understanding of the 'How to?' and identifying the resource bundles, there are Airport Security Officers (ASOs) who operate the body scanner equipment which itself consists of the body scanner and a separate and private viewing area. The body scanner requires a minimum of one ASO to operate, select and screen passengers and another ASO to view the body scanner image and assess. Developing an understanding of the 'What is?' there is a requirement to assess a classified[65] number of passengers ensuring screening is completed to DfT requirements.

Supporting the 'How to?' delivering the 'What is?' are the control documentation and information systems which are made up of a very detailed Security Standing Instruction. This document is used for reference when training the ASOs and is owned by the Airport Head of Security who ensures the instruction matches both the requirements of the DfT and the Airport.

Also influencing the body scanner process are the more generic but internal to the Airport process inputs. For example, the body scanner is just one element in the security screening process at the Airport where currently passengers are screened through the more familiar walk-through archway metal detectors (AMDs) in parallel to having their hand baggage screened through an x-ray machine. Another internal influence is the effectiveness of training of the ASOs in the use of the body scanner. During the body scanner implementation on the job training was given to the ASOs based around following the Security Standing Instruction.

External to the body scanner process are inputs which are very difficult to influence and in most cases impossible. For example, the DfT set requirements for security which must be met. These requirements as already discussed are translated into an internal procedure which is operationalised through the security process at the Airport. One of the key external influencing factors in this process is the passengers.

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[65] The Airport security team were very keen to keep certain aspects of the security process confidential in a bid to sustain the security process integrity.

The diversity of these passengers ranges from male or female; young children to senior citizens; with or without hand baggage; mobile or with limited mobility. There was also a cultural perspective which had to be understood with examples of some religions having concerns over the intrusiveness of the body scanner images as well as the segregation of individuals away from their family members. This caused some issues and the security team had to implement a mandatory policy where there was no flexibility and if the selected passenger refused to be scanned, then they would not be allowed to travel.

Establishing a measure of the body scanner process relating back to the 'Why?', the measure(s) must focus on understanding the process throughput to quantify process variation which in turn informs the future capacity planning requirements. Due to the combination of people (ASOs) and plant (the body scanner equipment) the first measure of choice was Overall Equipment Effectiveness (OEE). However, OEE was seen as not appropriate to this application as there was not necessarily a fixed cycle time -as you would find in a manufacturing environment- to measure performance. Also, as the integrity of the process means there is no room for error, the quality element of OEE measuring net yield was also not appropriate. In summary, the security process for body scanning passengers has no fixed cycle time as the process takes as long as it takes to confirm the passenger has been screened correctly. Therefore a different measure of the repetitive process was needed based around understanding the variation in the process.

Developing a measure of variation for the body scanner using the process stages identified in the SIPOC diagram, a value stream mapping analysis was completed by the Author to understand the value adding (VA), Non-Value Adding (NVA) and Necessary but Non-Value Adding (NNVA) contributions. Figure 65 is a development of the SIPOC shown in Figure 63 illustrating the results of the value stream mapping exercise including improvement suggestions as captured by the Author. Also shown are the average times taken during the observation to complete the individual process steps.

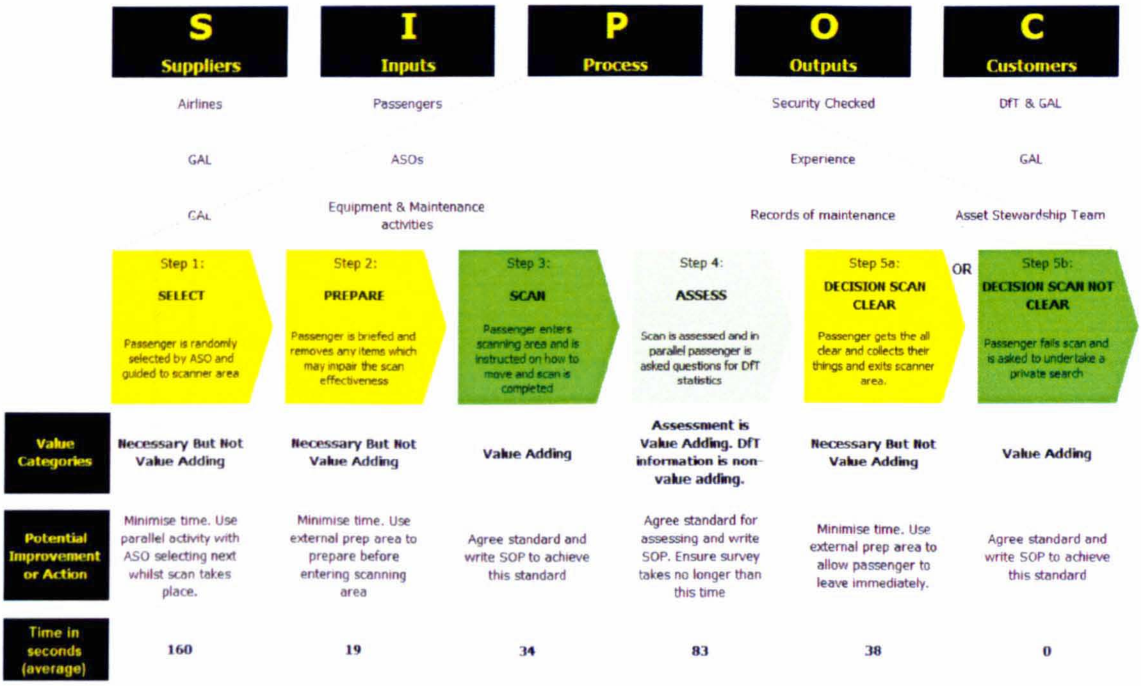

Figure 65: Value Stream Mapping Analysis

Adding these process step times gives the total average time to complete the body scanner process which could be used as a measure of process variation, the mean time between scans.

Mean Time Between Scans (MTBS) = Operating Time/Number of Scans (23)

With a proposed measure of process variation the next stage was to identify the data capture system and whether to keep a manual record or look to incorporate some kind of automatic data capture system linked to the body scanner equipment. As described in Step 4 of the process there was already a manual logging process recording the date, time of scan and other classified information (not relevant to this study). This information was also transferred onto a spreadsheet for data analysis in relation to information required for the DfT.

Using the information already being recorded and adjusting the format in the analysis spreadsheet it was possible to establish the mean time between scans without any additional data capture.

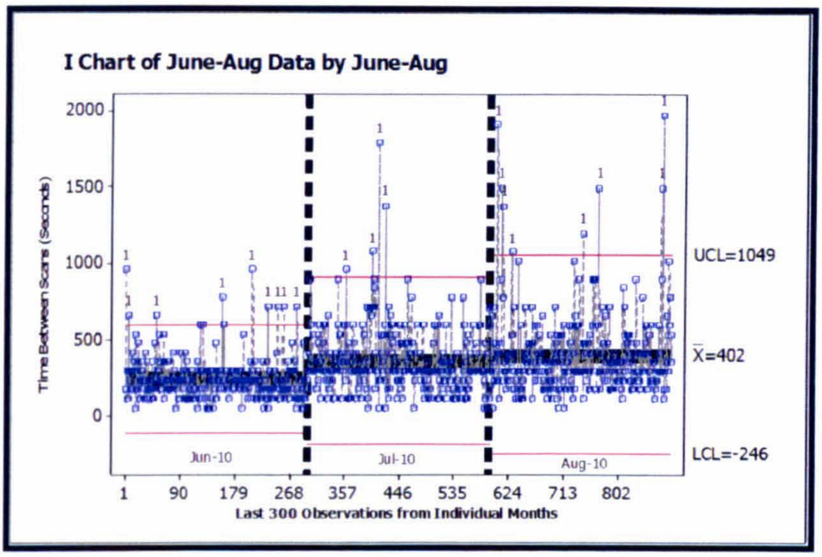

Figure 66: Body Scanner Process Variation

Figure 66 shows the body scanner process variation in run chart format using the last 300 MTBS values for the months of June, July and August presented by the Author. The body scanner was introduced in June and on-the-job as well as classroom based training was provided to operators over the first month of operation. Interpreting the data in Figure 66 there is clearly an increase in MTBS month-on-month which is unusual as processes would normally be expected to stabilise over time with variation reducing, not increasing.

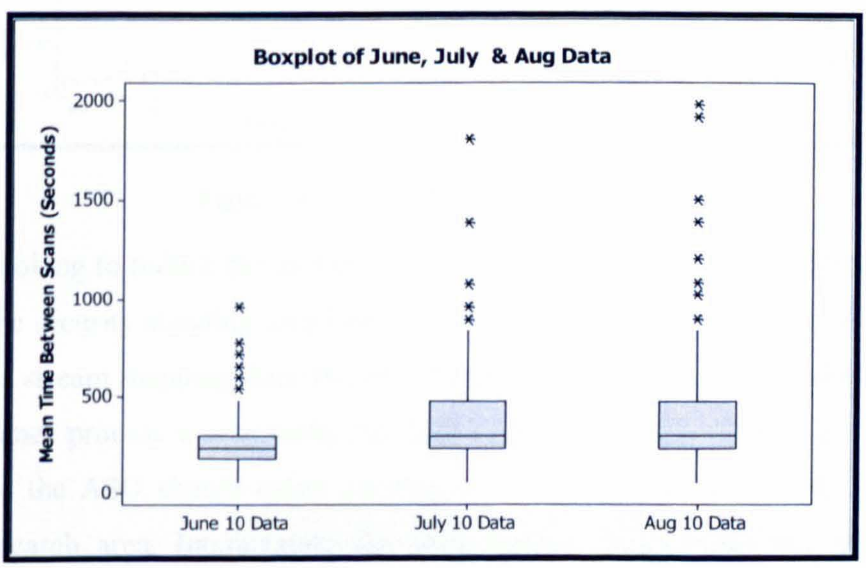

Figure 67: Box Plot of MTBS over Three Month Period

This can be seen more clearly in Figure 67 where the Author shows the highest value for June was approximately 1000 seconds rising to 1750 seconds for July and to 2000 seconds for August.

The data from the study was found to be none normal using the Weibull probability plot method with a 'P-value'[66] of <0.01. With this in mind a non-normal capability analysis was made using the upper and lower specification limits of 300 and 600 seconds respectively. Although there was no set target rate for completing the scanning process an upper specification limit (USL) of 600 seconds and a lower specification limit (LSL) of 300 seconds were agreed as easily achievable based on the observations of the ASOs when they followed the SSI procedure correctly. The results of the capability study are shown by the Author in Figure 68 which indicates the process is not able to match the USL and LSL with a Pk[67] of 0.26 and a Ppk of 0.02.

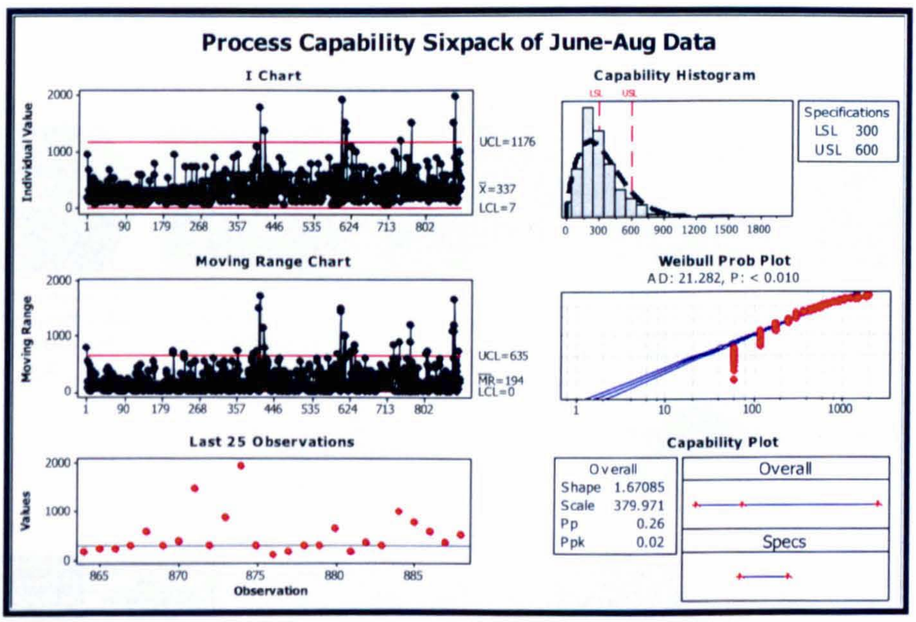

Figure 68: Capability Study of MTBS

Looking to reduce the variation and stabilise the process, reference was made back to the security standing instruction (SSI) and to the value stream mapping data. The value stream mapping data showed that 48% of the time spent completing the body scanner process was actually the time taken to select the passenger. The SSI states that the ASO should select passengers as they are about to exit the central security search area. Interestingly the observations showed that the ASOs were actually selecting passengers from wherever they felt was best. Although this was

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66 'P-value' is commonly used in statistics to represent the level of data normality. Data is typically classified as normal when the P-value is > 0.05 (Pyzdek, 2003).

67 Pk and Ppk are the process performance indices rather than the process capability indices Cp & Cpk (Pyzdek, 2003).

acceptable it was not following the SSI and also meant there was considerable variation in the time taken to select passengers. Therefore to reduce the variation and also reduce the MTBS a way of ensuring the ASOs were following the SSI instruction was needed.

In a manufacturing process a one page standard operating procedure (SOP) is typically used as a reminder to the process operator of the main steps to follow as well as any relevant health and safety and environmental hazards they should be aware of. This approach is standard practice in manufacturing sectors but not used in the security process.

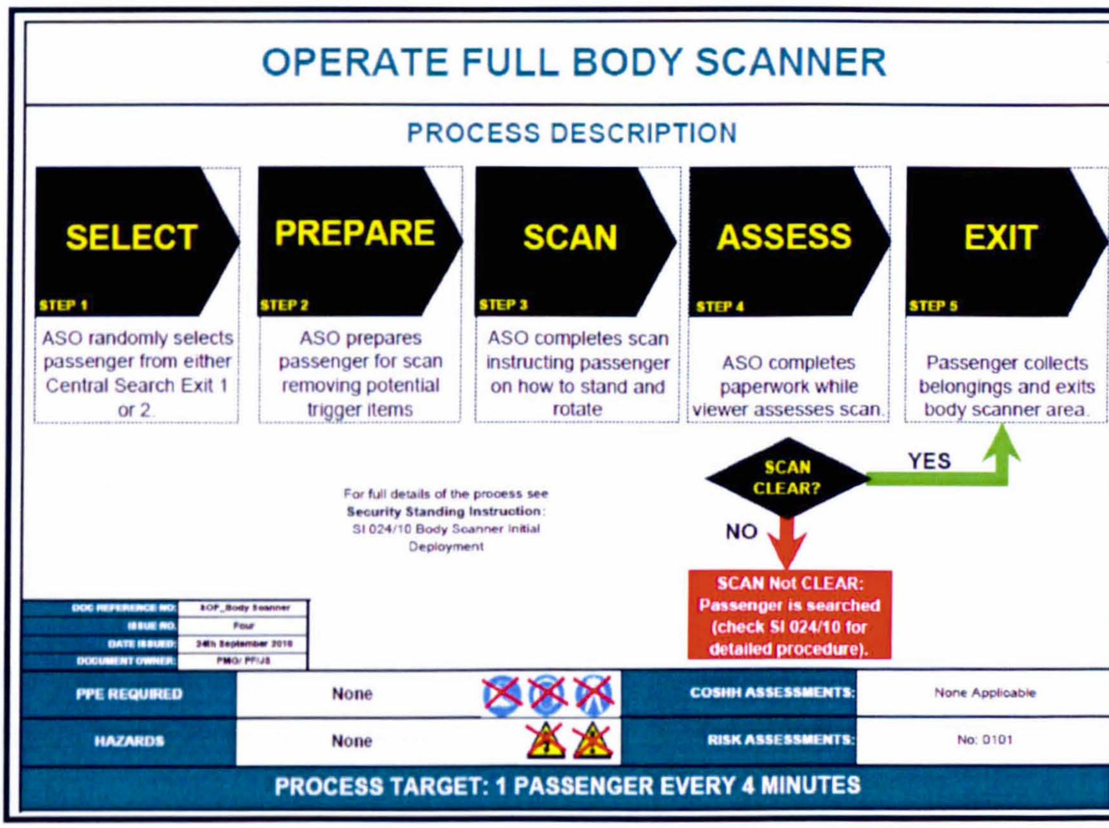

Figure 69: Body Scanner SOP

As a potential solution to the variation problem, Figure 69 is a SOP created by the Author to remind the ASO of the main steps in the body scanner process including a target pace for the ASO to work to. In particular step 1 specifically instructs the ASO to randomly select a passenger from exit 1 or 2 of the central security area. Critical to the implementation of the use of an SOP is the location it is displayed and any supporting communications and training to users. Bearing this in mind the SOP was displayed in the viewing area as in this location the ASO has time to read the SOP whilst the partnering ASO selects and prepares passengers for the scan. The key point here is that the ASOs rotate between duties and the ASO currently viewing will at some point be selecting and preparing passengers for the scan.

In parallel to displaying the SOP in the viewing area a short communication was prepared for inclusion in the daily brief to the security teams. Finally, ASO trainers were also informed of the SOP and included this for reference in any additional training carried out on the body scanner equipment.

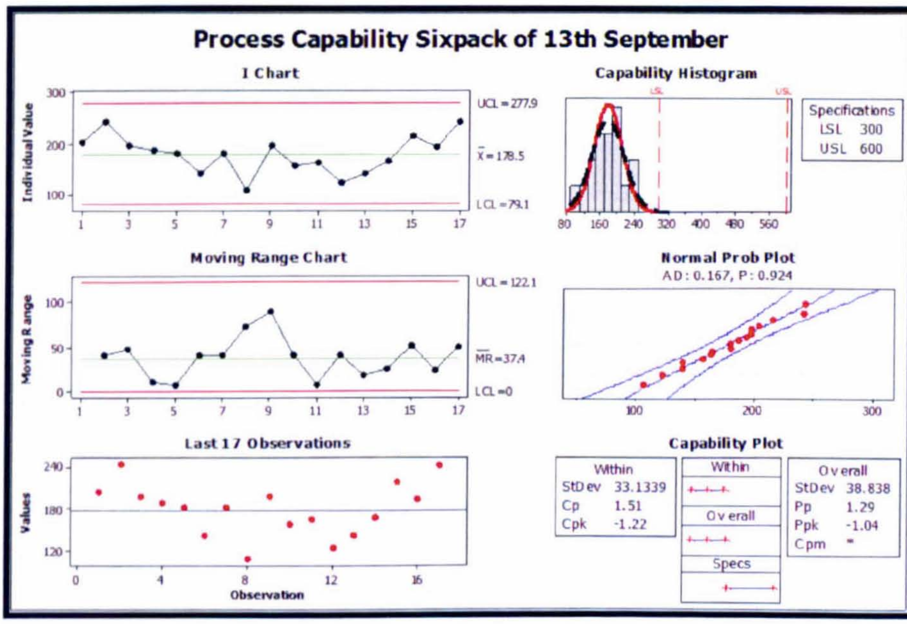

Figure 70: Capability Study after SOP Implementation

Checking the effectiveness of the SOP implementation -taking into account the value improvement model for the body scanner process- The Author presents Figure 70 which shows the results from an observation of the body scanner process when the ASOs are following the one page SOP. The results indicate the process is now showing a normal distribution (P value is 0.924) and the process variation is at 1.51Cp (un-centred process capability) with a MTBS of <180 seconds. The process Cpk (centred process capability) is showing a minus value of 1.22 due to the upper and lower specifications being outside the MTBS. In this example the process has far exceeded the desired performance of 300 lower specification limit (LSL) to 600 upper specification limit (USL) seconds to complete the body scanner process[68].

[68] This is an interesting point and six sigma specialists would suggest the USL and LSL should be changed to show the Cpk value at a higher level of capability. The author disagrees with this approach and has interrogated the data to understand that the process has far exceeded the expectations of the

As this format of process control had not been used before in the security process a simple survey sheet was also issued at the same time as the SOP was implemented. The survey sheet asked 2 questions and also had a space for comments on how the SOP could be improved. The response to the survey was limited with only 29 of the ASOs working the body scanner completing a survey sheet. However the survey responses, though limited are of interest.

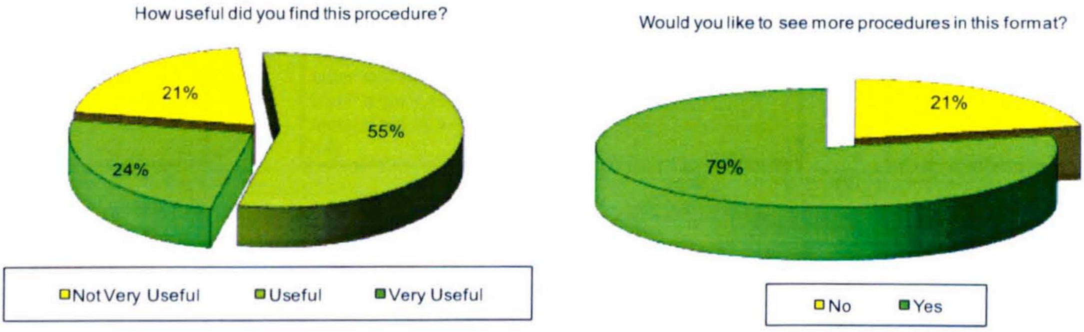

Figure 71: SOP Survey Results

In Figure 71 the Author shows the results of the survey where 79% of the respondents said they would like to see more procedures in this format and also a total of 79% of the respondents said they found the procedure either useful (24%) or very useful (55%).

Interestingly, the SOP form introduced was initially not seen as useful in the eyes of the security management team. However, after the feedback from the survey results and improvement in the body scanner performance, the security management team are now using the SOP format on other security processes. In Figure 72 the Author shows an example of how the SOP format has been applied to other processes in the security process based on the success as part of this investigation.

customer and when this occurs the Cp value should be used as an indicator of process capability and not the Cpk. The author believes this kind of issue to be one of the weaknesses in the six sigma approach to process improvement where statistics are being interpreted based on the numerical value alone without understanding the purpose of the investigation.

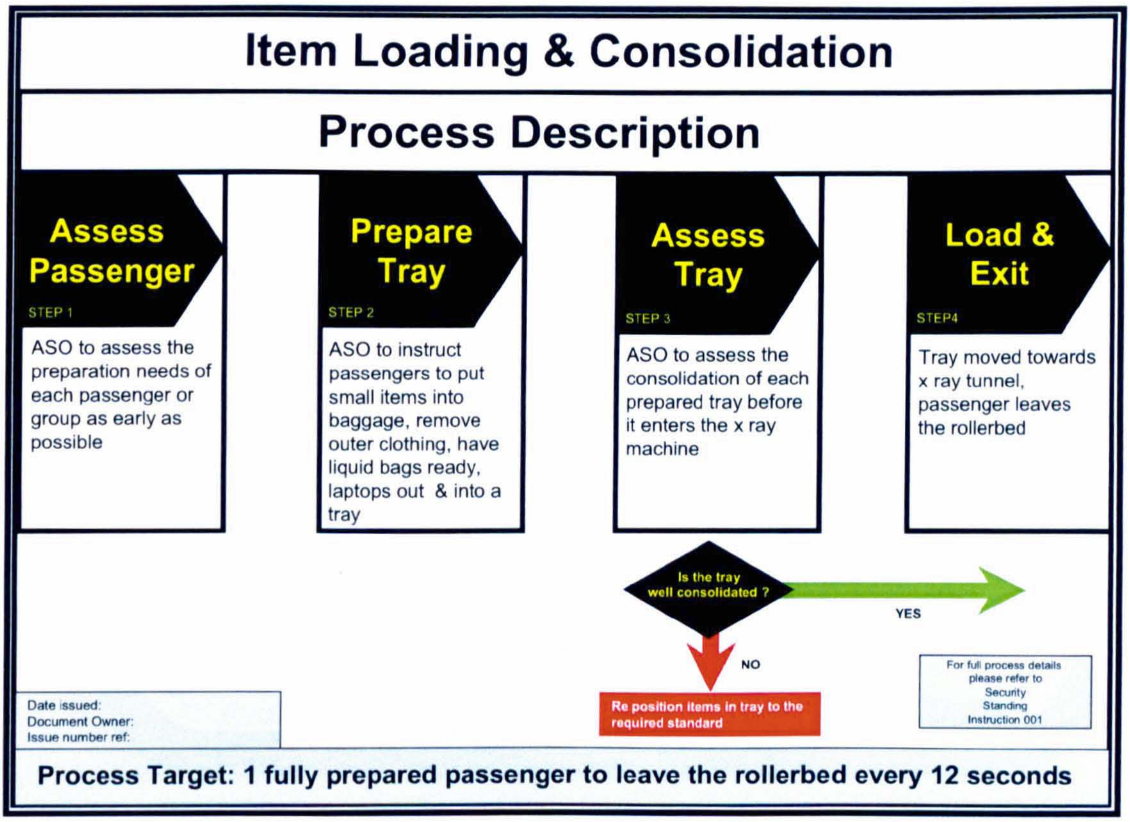

Figure 72: SOP Developed for Security X-Ray Process

8.3 Discussion

R6. Can the manufacturing value improvement model be adapted for use in a service industry environment?

The value improvement model for repetitive processes has been successfully applied to the body scanner security process within a busy international Airport. As was discussed in the case study example, OEE was initially reviewed as a measure in the value improvement model but was not seen as suitable due to the performance and quality elements of the calculation. In particular, the quality element was not applicable as the integrity of the security process was critical and therefore the quality element would always be 100%. Therefore an alternative measure of performance was developed based around the mean time to scan passengers giving an indication of the process capability and potential throughput informing future development plans within the Airport.

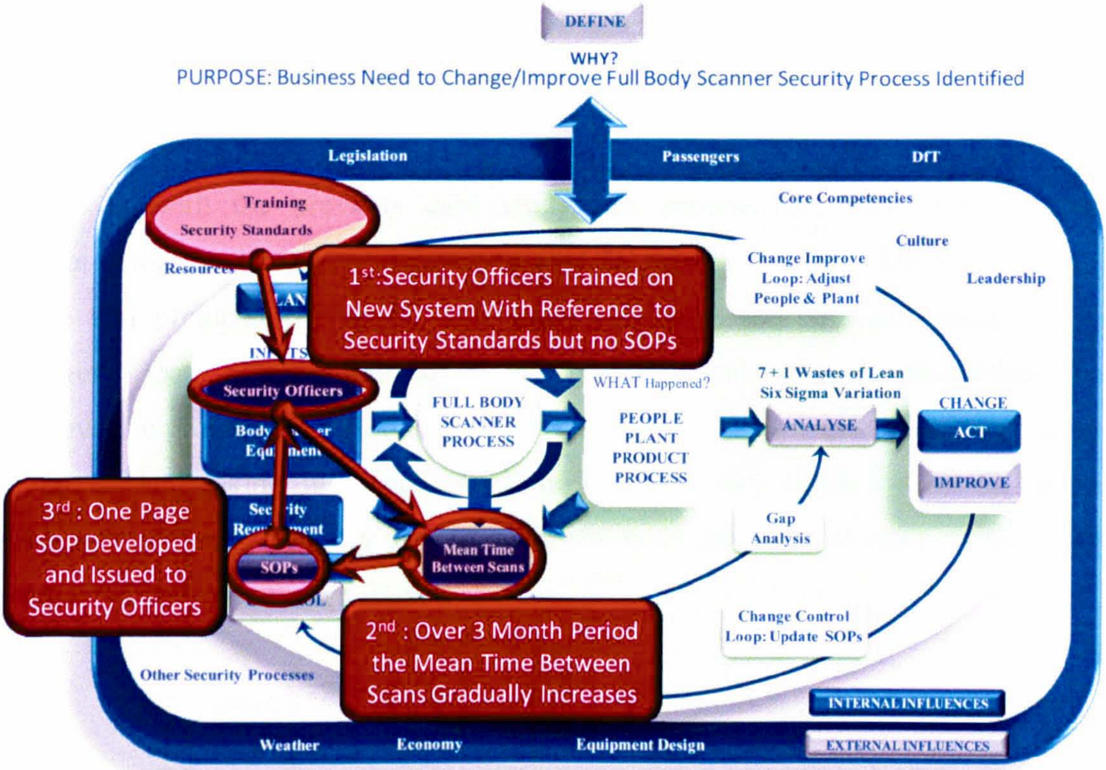

Figure 73: Body Scanner SOP Value Improvement Contribution

In Figure 73 the Author shows the body scanner value improvement model overlaid with the following discussion points:

- The security officers were initially trained on the job with reference to a nineteen page security standard instruction which after the training was kept locked away for security integrity purposes.
- Over a 3 month period after the initial implementation and training of the new equipment, the mean time between scans gradually increases along with the variation of scan times.
- Looking to overcome the increase and variability in scan times, a one page SOP was introduced to the security officers and displayed at the scanner equipment location for quick reference.

The introduction of a one page SOP resulted in an improvement to the process reducing the MTBS from >420 seconds before the VIM implementation to a MTBS of <180 seconds. The process variation also improved to a Cp of >1.5. This information could now be used to plan the future capacity requirements of the security process using data based around a statistically proven capable process. However, as observed in the external influencing factors, there are other processes and factors which influence this process which must be considered if any changes are to be made to the Airport security process in the future.

8.4 Conclusion

As with the previous case study this process has been improved by standardising the repetitive process applying 5S principles to the development of a stable and predictable process. This again reinforces the argument presented in Chapter 5 that 5S is the foundation for any sustainable process improvement. To improve the process even further the lean resource mapping framework would need to be applied taking into account all of the resources employed in the entire passenger screening security processes shown as an internal influence on the body scanner value improvement model.

Chapter 9: Applying the Value Improvement Model to Engineering Operations Using Systems Thinking

9.1 Introduction

The preceding case studies have shown how the value improvement model can be used to improve repetitive processes in both manufacturing and service industry environments. However, as was noted during the Airport body scanner value improvement model development, the manufacturing measure of OEE is not always suitable and therefore the value improvement model should be further developed to make it more generic so it can be used in any application where repetitive processes are present.

This section of the thesis is also based around published material. The first paper was presented at an asset management seminar in a joint venture between the Institution of Engineering & Technology (IET) and the Institution of Asset Management (IAM) held at the IET building in London, September 2010 (Gibbons and Kennedy, 2010). The paper shows the development of the value improvement model for sustainable asset management. The concepts developed in this paper where written up in a format suitable for publication in an International Journal and has subsequently been accepted for publication in the International Journal of Quality & Reliability Management (Gibbons *et al.*, 2011a).

Therefore this section of the thesis will look to further develop the value improvement model using systems thinking as part of an action case study investigation of asset management effectiveness within an Airport operational engineering environment[69]. As businesses look to do more with less money the balance between acceptable levels of asset governance and asset management continuous improvement becomes more critical.

9.2 Airfield Engineering Case Study

The concept of historical measures of asset management are introduced as a key element in this value improvement case study identifying opportunities to change the resource bundles and other process inputs in a sustainable and effective way. Although the historical measurement of asset effectiveness seems logical and

[69] This is the infrastructure engineering including buildings, HVAC, passenger transfer, runway and taxiways. It is not the engineering of aeroplanes.

appropriate, previous attempts to implement this methodology had not been 100% effective within the airfield engineering team.

Seeking to overcome this problem, the soft systems methodology (SSM) (Checkland, 1981; Checkland and Scholes, 1990) is introduced as a useful and complementary methodology to the extant traditional scientific and more hard systems paradigms for implementing effective asset management as proposed by Kelly (1988; 1997; 2001; 2005).

CATWOE Element		Definition
C	Customer	The affectee(s) of the transformation process
A	Actors	The agents and their specific core-competences participating in the transformation process
T	Transformation Process	Transformation process of 'needs for' into 'needs met'
W	World view	The 'Weltanschauung' making the transformation process meaningful from the different affectees perspectives
O	Owner	The decision maker with power and responsibility for the overall performance of the system.
E	Environmental Constraints	The internal and external environmental constraints influencing the transformation process

Table 18: CATWOE Definitions

This section of the thesis will encompass a taxonomic and captious review of the SSM literature focusing on the CATWOE (Customers, Actors, Transaction Process, World View, Owner & Environment) approach to developing a problem root definition and conceptual model of the asset management process for airfield stands[70] (see Table 18: CATWOE Definitions for an overview of this approach). Using an action case study approach, a conceptual model is presented illustrating

[70] The stand areas are where planes are guided to offload passenger and their luggage either directly into the terminal building or via a coach to the terminal building. At the Airport where this study was completed there are over 150 stands each with a similar set of assets.

how the value improvement model for sustainable asset management was developed and how the SSM CATWOE approach was applied to the implementation process. Discussing the usefulness of the approach and research limitations the final section introduces key learning points which can be carried over to further developments of this SSM approach to improving sustainable asset management and the development of a more generic value improvement model for repetitive processes.

9.2.1 Soft Systems Methodology & CATWOE

Checkland (1981) originally represented SSM as a seven-stage cyclic, learning system (Jackson, 2003) which was later updated to a two-strand version (Checkland and Scholes, 1990) overcoming criticisms found with the flexibility when using the seven-stage model (Mingers, 2000). However, although the seven-stage model has been superseded, Jackson (2003) argues the approach is still frequently used today and therefore the suitability of this approach will be reviewed for this investigation.

The seven-stage model introduced by Checkland (1981) is based around first gaining an understanding of the problem situation in the real world, through steps 1 & 2. Then the development of root definitions and concept models using systems thinking about the real world can be made through steps 3 & 4. Finally, the comparison of systems models with the real world and identifying changes and improvements to the problem situation, through steps 5, 6 & 7; completing the learning cycle.

The main difference to a hard systems approach is the ability to develop different root definitions and concept models based around different viewpoints resulting in a number of models to be compared to the real world (Jackson, 2003). For this research investigation steps 3 and 4 of the methodology *"root definitions of relevant systems"* & *" conceptual models of the systems"* (Checkland, 1981) will be focused on; in particular the CATWOE tool will be used to gain a holistic view of the problem statement and different viewpoints (Smyth and Checkland, 1976).

As Bergvall-Kareborn *et al.* (2004) argue, CATWOE does not represent reality but it can be used to learn about social reality and more applicable to this investigation, Checkland and Scholes (1990) suggest CATWOE offers greater specificity which can lead to more useful models in most situations.

Bergvall-Kareborn *et al.* (2004) suggest the CATWOE modelling technique has remained unchanged since its introduction in 1976 (Smyth and Checkland, 1976) and that considering the wide usage of SSM in real-world analysis and intervention this suggests the technique is *"strong and captures important issues useful to consideration in modelling"*. This suggests the CATWOE tool may be useful to developing the value improvement model used in this investigation.

Reviewing the CATWOE mnemonic elements as originally proposed by Smyth & Checkland (1976) the first element is focused on the 'Customer' who Smyth & Checkland suggest can be either the client, beneficiary or victim of the activity or alternatively be the sub-system affected by the activity. Jackson (2003) simplifies this to just the beneficiaries or victims of the transformation process (T) itself.

Bergvall-Kareborn *et al.* (2004) present a warning that the customer should not be confused with the everyday use of the word where the customer is the recipient or purchaser of goods. Developing a more practical and specific definition which can be used at multiple levels of abstraction and building on the work of Mingers (1992), Bergvall-Kareborn *et al.* (2004) propose the customer of T as the *"Affectee"* arguing the term naturally reflects both victims and beneficiaries. For the purpose of this investigation the customer(s) will be the affectees of the transformation process.

Smyth & Checkland (1976) introduce the 'Actor' in CATWOE as the agents who carry out or cause the transformation process or any activities of the system. Again, Jackson (2003) simplifies this to those who undertake the transformation process (T). Bergvall-Kareborn *et al.* (2004) initially simplify this further stating the actor is defined as *"those that would do T"* but then develops the definition to be more practical suggesting the actors are *"those who would carry out the activities of the process, including their specific competence(s)"*. For the purpose of this investigation the actor(s) A will be the agents and their specific core-competences participating in T.

Smyth & Checkland (1976) introduce the Transformation (T) as being at the core of the root definition and is the transformation process carried out by the system. Simplifying this definition Jackson (2003) proposes T is the conversion of input to output. Bergvall-Kareborn *et al.* (2004) concur suggesting traditionally T is defined as the transformation of some input to some output but warn consideration must be made to a common error when defining T where the input is seen as the resources which are needed to carry out the transformation process. Overcoming this problem Bergvall-Kareborn *et al.* (2004) present a useful definition which will be used in this investigation where T is the transformation process of *"need for X → T → need met"*.

Smyth & Checkland (1976) introduce the World View (W) as *"Weltanschauung"* defined as the outlook or taken-for granted framework making the root definition meaningful. Jackson (2003) concurs arguing Weltanschauung is the world view that makes the transformation meaningful. Mingers (2000) suggests the concept of Weltanschauung is a key element of SSM and CATWOE and all diagrams of human system elements must represent particular viewpoints. Bergvall-Kareborn *et al.* (2004) also add that along with understanding what makes T meaningful, the Weltangschauung should also consider the beliefs of the root definition.

Attempting to overcome some of the criticisms of W especially the confusion caused by the many senses used during SSM development, Checkland & Davies (1986) introduced three different levels of W:

W1: Relates to the W in CATWOE and the overall 'given as taken' set of assumptions

W2: Relates to a version of W1 making it relevant

W3: Relates to the beliefs and assumptions about reality

For the purpose of this investigation the Weltanschauung definition will encompass Checkland & Davies (1986) W1, W2 & W3 and is classified as the W making the transformation process meaningful from the stakeholder perspective which, using the definition for C in this investigation, could be any of the affectees of the T.

Smyth & Checkland (1976) introduce the Owner (O) has having ownership of the system and control, concern & sponsorship. Simplifying this definition, Jackson (2003) proposes the owner(s) are those who could stop the T. This simple definition is also put forward by Checkland & Scholes (1990) & Bergvall-Kareborn *et al.* (2004). As with the customer element of CATWOE, the owner has other meanings which can confuse the development of an accurate root definition. Overcoming these criticisms Bergvall-Kareborn *et al.* (2004) present a useful definition which will be used in this investigation where the owner is defined as the decision maker with power and responsibility for the overall performance of the system.

The final element of the CATWOE mnemonic is Environmental Constraints (E) which Smyth & Checkland (1976) introduce as the environmental impositions, interactions with wider systems where these systems are taken as given. This simple definition is also replicated in the literature by Checkland & Scholes (1990), Jackson (2003) & Bergvall-Kareborn *et al.* (2004). However, Bergvall-Kareborn *et al.* (2004) elaborate further suggesting the environmental constraints can be better understood by splitting into two categories, determinative and normative constraints.

Bergvall-Kareborn *et al.* (2004) argue determinative constraints relate to the natural world and are things such as weather and volcanic activities (these are particularly relevant to an Airport operation) and normative constraints are socially constructed and therefore can be changed. Developing a definition for this investigation the environmental constraints are defined as the internal and external environmental constraints influencing the T.

In Table 18 the Author has summarised the taxonomy of descriptions for the CATWOE mnemonic elements based on interpreting extant definitions by Smyth & Checkland (1976); Checkland (1981); Checkland & Davies (1986); Checkland & Scholes (1990); Mingers (1992; 2000); Jackson (Jackson, 2003) & Bergvall-Kareborn *et al.* (2004) providing a useful reference table to be used for this investigation.

Visualising the CATWOE approach, in Figure 74 the Author shows how the individual elements are connected as a systems map. The transformation process 'iTo' is shown in the centre receiving inputs from the actors 'A' and providing outcomes of the transformation process to the customers 'C'. The owner 'O' is shown bridging the transformation process system boundary and the environment 'E' sits outside the transformation process encompassing determinative and normative constraints. Finally the Weltanschauung is shown sitting externally to the system map providing different perspectives to view the transformation system map.

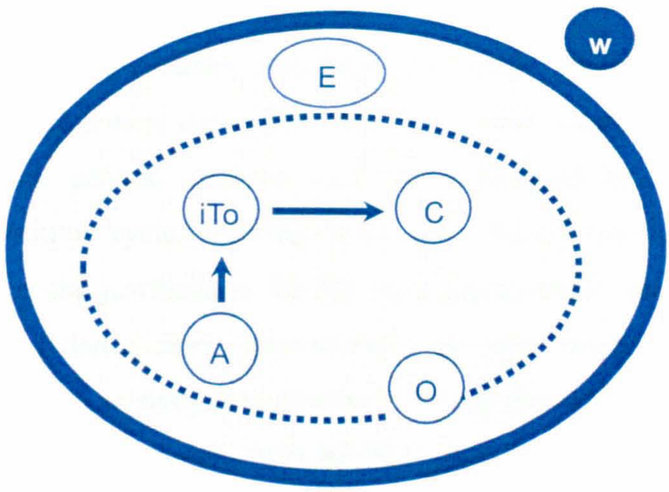

Figure 74: CATWOE System Map

9.2.2 Airfield Case Study

The asset management effectiveness investigation using a soft systems approach was carried out in a busy international Airport focusing on the assets found at the Stand area of an airfield. Using an action research approach to developing a suitable research design for this situation, the first stage was to build upon the generic VIM to create a value improvement model for the asset management process and then to understand where and how the historical measures of asset management can be used.

Developing this model the researcher was embedded within the organisation taking an overt ethnographical approach working closely with the key stakeholders within the business. Once the VIM for asset management was developed a soft systems approach to implementing the historical measures was applied focusing in on using the CATWOE tool for developing a root definition of the problem area. As previously argued, the CATWOE tool provides a holistic model capturing important information to be considered (Bergvall-Kareborn *et al.*, 2004) and gives greater specificity to problem and development of useful models (Checkland and Scholes, 1990).

The following sections show the case study example of the VIM for asset management and the use of SSM CATWOE for developing a conceptual model for the implementation of lagging measures of asset management effectiveness.

9.2.3 VIM for Sustainable Asset Management

In Figure 75 the Author illustrates the value improvement model for sustainable asset management developed from the 1st draft working model presented in Figure 54. The generic sections have been changed to reflect the asset management repetitive cycle. Starting with the 'Why?' and purpose for the improvement cycle, the justification for the asset management improvement comes from the need to balance asset governance with asset management continuous improvement. For the case study this was the first time the value improvement cycle had been used and the why statement is based around setting up the process to run the repetitive cycle to gain a base-line measurement of asset management effectiveness to drive improvement. This baseline can/will then be used to set future targets for future value improvement cycles.

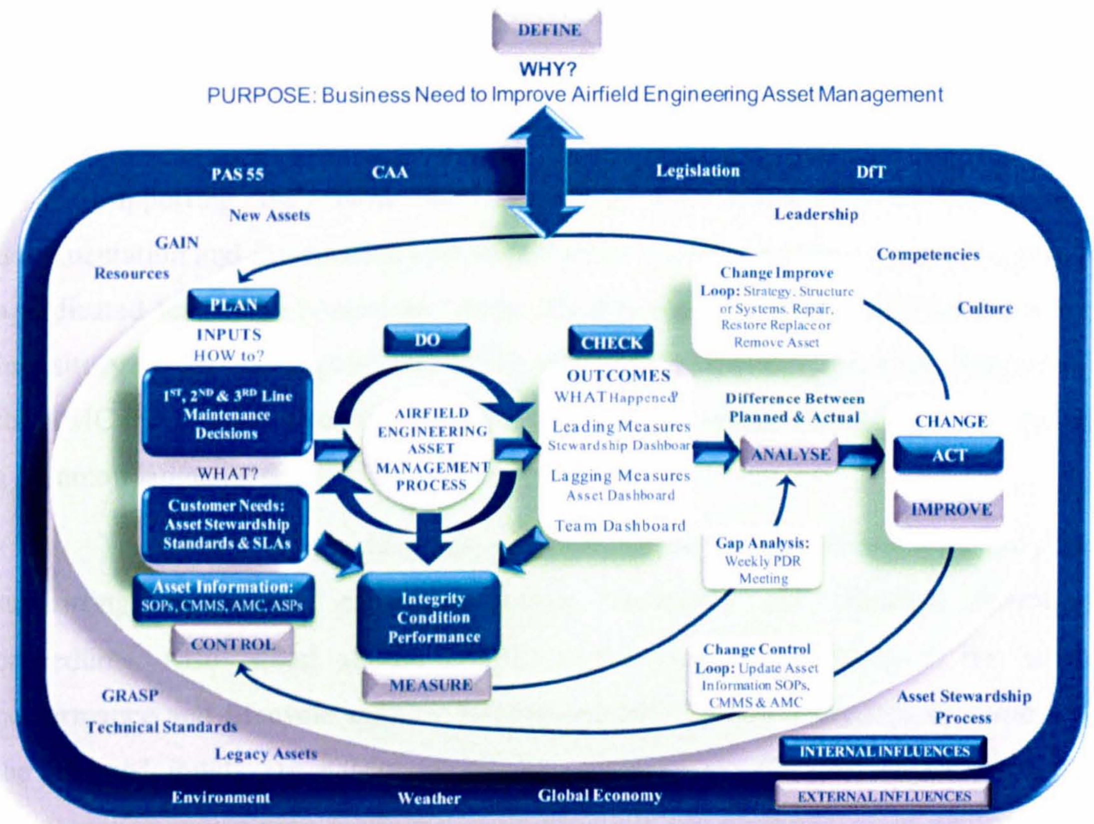

Figure 75: Value Improvement Model for Sustainable Asset Management

The planned inputs to the repetitive process focus on identifying the 'How to?' and the 'What is?' elements which are supported by controlling elements which help standardise these process inputs. Developing an understanding of the 'How to?', there are groups of maintenance engineering teams split by two main functions, civil/mechanical engineering and electrical/electronic engineering carrying out 1st, 2nd and 3rd line maintenance activities based around a pre-determined maintenance schedule and unplanned corrective maintenance activities.

The teams are based in the airfield with dedicated workshops with plant to support their maintenance activities. Developing an understanding of the 'What is?' there are three asset management requirements which are tailored to suit the needs of the customer sometimes documented as service level agreements. The first requirement is integrity, this is specifically '*...the ability of an asset not to give rise to unacceptable situations..*'[71] and is focused on assuring Health, Safety, Security and the Environment. The second requirement is performance, this is specifically, '*...the ability of an asset to perform to meet the business need..*'[72] and is focused on the passenger and their baggage assuring their journey through the Airport process is not compromised due to asset failure. The third requirement is condition, this is specifically, '*...the probability that performance will be maintained in the future...*'[73] and is focused on balancing the cost of maintenance against the two other requirements of performance and integrity.

Supporting the 'How to?' delivering the 'What is?' is the control documentation and information systems which are made up of two areas. The first is a dedicated team who control an 'Asset Management Centre' (AMC) which is the repository for all drawings and technical information related to the asset. Supporting the AMC is a computerised maintenance management system (CMMS) based around a common language document for categorising assets.

The CMMS is used to control maintenance activities and is a repository for supporting information such as method statements and standard operating procedures. Also stored on the CMMS is historical data relating to the assets performance and lifecycle such as breakdowns and corrective repairs. In summary, the planned inputs are based around the strategy, systems and structure of the maintenance engineering work groups providing a service to the asset management repetitive process.

Also influencing the airfield asset management process are the more generic but internal to the Airport process inputs. For example the technical leadership

[71] Developed from the Airport asset stewardship standard for Integrity.
[72] Developed from the Airport asset stewardship standard for Performance.
[73] Developed from the Airport asset stewardship standard for Condition.

provides standards which must be adhered to influencing maintenance requirements to fulfil expectations for various types of asset such as electrical circuits, water supplies and HVAC systems. Another internal influence is the culture of the Airport personnel and the impact this may have on workforce morale and motivation to complete maintenance activities. This is influenced by the use of both employed and sub-contract labour which can cause conflict if not managed correctly.

An important influencing factor is the business strategy and approach/attitude to asset management. During the development of this case study the Airport was closed for over a week due to the volcanic ash cloud (a good example of an external influence) and during this time the opportunity arose to complete many maintenance activities which could not normally be completed during normal working hours.

For example, the main runway -which is the prime asset of the Airport and usually any down-time has to be carefully planned in so as not to reduce income- was available for line marking, lighting replacement, aircraft tyre rubber removal and other maintenance activities at any time. However, the volcanic ash incident also had a negative effect on the asset management as due to reduced income, budgets were later cut across the Airport including a large reduction in the asset management budget which itself influences other internal factors such as morale and ability to meet technical standards.

In summary, the internal influences to the asset management repetitive process can be either negative and/or positive and they are also not mutually exclusive.

External to the airfield asset management process are inputs which are very difficult to influence and in most cases impossible. For example, the volcanic ash incident was an environmental incident which was impossible to influence as an asset management process. However, pressure from many Airport and Airline leadership teams across the country influenced a change in the criteria for flying during the volcanic ash incident leading to the Airports reopening under restrictions based around cloud density.

Another external influencing factor to the Airport operations and asset management are the guidelines provided by the Civil Aviation Authorities (CAA) in particular the licensing of aerodromes document (CAP168) which stipulates the asset management requirements of airfield assets such as the aerodrome ground lighting (AGL) systems providing visual guidance for aeroplanes either in the air on the ground. The CAA guidelines as well as other legislative documents are typically used to write internal specifications previously introduced as technical standards.

A measurement framework must be developed to understand what happened specifically to the people and plant producing the product which in this case will be the asset management requirements from the perspective of the internal and external customers. Developing a more generic measurement framework than the previously proposed use of OEE in the manufacturing value improvement model, Checkland & Scholes (1990) introduce the 3Es, efficacy, efficiency and effectiveness as three useful measure of the transformation process T.

Developing useful definitions for the 3Es from antecedent work by Checkland & Scholes (1990) & Checkland (1999), efficacy can be defined simply as 'does the repetitive process work?', efficiency as 'the output divided by the input, are we good at the repetitive process?' and finally effectiveness as 'is the repetitive process matching the longer term aim and are stakeholders satisfied?'

Outcomes of the asset management process are measures based against three specific areas:

1. Leading measures; the asset management activities completed to assure governance including setting up the assets within the asset management process (assess criticality, performance & work plans requirements for example). A scorecard matched to nineteen asset management procedures and three asset management requirements has been developed to measure this by asset group with governance sign-off made by the asset steward.
2. Lagging measures; the historical measures of asset effectiveness directly corresponding with the asset management requirements of Integrity, Performance and Condition. Information is used in annual review of asset management effectiveness and used to inform asset replacement plans and improvement opportunities.
3. Team dashboards; the day-to-day operational performance of the asset management work groups including work carried out against plan and work

efficiency and cost. Information is used at weekly 'plan, do and review' meetings to drive improvements.

The lagging measures of asset effectiveness are the focus of this investigation and therefore the definitions and calculation methods are reviewed in more detail

Asset Performance

The asset management requirement definition of Performance is 'The ability of an asset to perform to meet the business need'. This requirement is customer/passenger centric and based on ensuring flow through the Airport is not compromised in the terminals and on the airfield. The measure of Performance is availability indicating a percentage rating of the actual uptime against the planned uptime.

$$(\text{Planned Uptime} - \text{Downtime}) / \text{Planned Uptime} \times 100\% \qquad (24)$$

Asset Condition

The asset management requirement definition of Condition is 'The probability that performance will be maintained into the future'. This is cost/performance/integrity centric with three separate indicators used to understand the cost effectiveness of the asset helping to answer the question when is the best time to remove, repair, restore or replace the asset.

		Asset Function Code Groups on Pier 'X'												
Category	Description	Fixed Electrical Ground Power	Stand Entry Guidance	Fuel Hydrants	Fuel Hydrant E-Stop & SEG Control Panel/E-Stop	Barriers	Fod Bins	Telephones	Fire Hydrant	Saw Dust Bins	Flood Light	Storm Water Drainage	Pavement	3rd Party Assets
Electrical Rating (if applicable)	What is the electrical integrity of the asset based on the likelihood of safety or service failures?													
Mechanical Rating (if applicable)	What is the mechanical integrity of the asset based on the likelihood of safety or service failures?													
Structural Rating (if applicable)	What is the structural integrity of the asset based on the likelihood of safety or service failures?													
Life Expectancy	What is the book life to expected life of the asset? Has it entered the wear out phase?													
Asset Obsolescence	Is the asset design now obsolete and spares are no longer available?													
Asset Fit For Purpose Status	Is the asset fit for purpose in the eyes of the end user customer													
Asset Environmental Rating	Is the asset environmentally friendly with respect to energy consumption and waste materials?													

Index Rating Key					
1	2	3	4	5	Index Rating Criteria: Probability of Delivering Good Service Over The Next 12 months
0% - 25%	25% - 50%	50% - 75%	75% - 100%	100%	

Figure 76: Asset Condition Rating Table for Stand Asset Types

The first sub-measure of Condition relates to the physical condition of the asset and is assessed against a subjective measure of whether the asset will deliver a good service over the next twelve months. In Figure 76 the Author shows their assessment template used with the asset type shown horizontally and the assessment criteria vertically.

The second sub-measure of Condition is based around the costs of maintaining the asset and includes all labour and overheads as well as the replacement part costs. Finally, the third sub-measure of Condition is based on the reliability of the asset deliberately ignoring any repair times as these are not part of the review (this is measured as part of the team dashboard). Asset reliability is assessed by calculating the mean time to failure of the asset measured in days between failures.

$$\text{Actual running time (days, excludes repair time) / Number of failures} \qquad (25)$$

Asset Integrity

The asset management requirement definition for Integrity is 'The ability of an asset not to give rise to unacceptable situations'. This is broken down into four areas of interest, Health, Safety, Security and Environment. Asset Integrity is assessed by calculating the mean time to an incident for the four areas of interest and is measured in days between failures. A failure is classified as the consequence of an asset failure which has led to an unacceptable situation occurring.

Health = Calendar period (days) / Number of Health failures (26)

Safety = Calendar period (days) / Number of Safety failures (27)

Security = Calendar period (days) / Number of Security failures (28)

Environment = Calendar period (days) / Number of Environmental failures (29)

The final element of the value improvement process is to analyse the outcomes against the requirements and change the inputs and controls (if needed) to drive improvement. For the asset management value improvement model this is carried out via a weekly improvement meeting where the team dashboard is reviewed and also via an annual[74] asset review meeting where the lagging and leading measures are reviewed.

Outcomes of the annual meeting determine the plans and actions for the year ahead as well as the updates required to the asset replacement plan. The annual review is held with the asset steward -with agreed accountability for the asset- who must physically sign off and approve the current state of the asset for Condition, Integrity and Performance. These three requirements form the basis for all asset management strategies and are matched to the specific requirements of the customer who use the assets to provide a service to their business process. At the formal review actions are agreed based around removing, restoring, repairing or replacing the asset as well making changes to the way the asset can be maintained through the asset management system, strategy and organisation.

Controlling any changes to the repetitive process inputs is a key element and standard operating procedures and method statements must be updated to reflect any

[74] The frequency is determined by the criticality of the asset with a default period of one year until the repetitive cycle has been completed for the first time.

changes to the asset management processes based on the previously discussed review process.

9.2.4 CATWOE Application to Asset Management of Airfield Stands

Using the definitions for the elements of CATWOE summarised in Table 18 and the VIM for sustainable asset management presented in Figure 75; the following section completes the case study concluding with a conceptual model of the asset management process for airfield stands which will be used to develop a template for lagging measures of asset management discussed in the final section. A reflection will also be made in the use of CATWOE for further refining the value improvement model for repetitive processes.

Customer (C)

The affectees of the transformation process can be defined as the Airfield Stand Managers (ASM) who coordinates the use of stands on the airfield. If there is an asset failure then they will have less capability to satisfy their customers (the airlines). The airlines are also a customer of the transformation process as they are dependent on stands being available to park their planes, to offload their passengers and bags and to service their own assets (basic maintenance activities to their planes such as re-fuelling).

Finally, the ground handling agents are also customers of the transformation process as they need the stands to be available to carry out their activities such as connecting planes to the ground services (such as secondary power), offloading/loading passengers/bags. Overall the Airport itself is also a customer of the transformation process as rents will not be paid for the use of the stands if they are not available for their intended use and the link with the Airport business perspective is made through the ASM.

Actors (A)

The definition for actors as previously defined suggested the actors are the agents and their core competences in the transformation process. With this is mind the actors and their core competences within the asset management process are defined as:

- The asset steward who has overall accountability for the assets;
- The facilities manager (FM) who oversees all maintenance work;

- The maintenance planner (MP) who links with the FM and prepares maintenance work plans (WPs);
- The facilities team leader (FTL) who links with the FM and MP to organise the delivery of the WPs;
- The technicians who carry out the WPs coordinated by the FTL.

Transformation Process (T)

The transformation process T for converting the 'needs for' into 'needs met' for this investigation is based around the asset stewardship process within the Airport. The previously discussed asset management requirements of integrity, performance and condition set against the customer needs are the input to T, the 'need for?' The transformation process is the actual asset management activities including 1st, 2nd and 3rd line maintenance activities and encompass the VIM for asset management presented in Figure 75. Finally, the output (needs met) are the outcome measures as leading and lagging KPIs against the customer need for Integrity, Performance and Condition of the T; the 'need met?' In Figure 77 the Author shows the: 'Need for' → T → 'Need met' for the asset management of airfield stands.

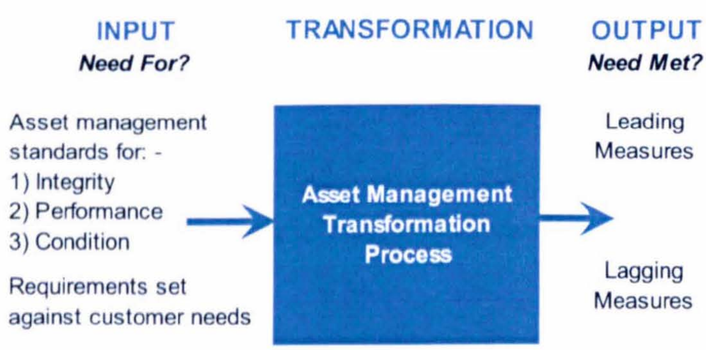

Figure 77: Transformation Process 'T'

World View (W)

The different world views are represented by the affectees of the transformation process. For this investigation the use of a generic Airport operating model is useful to understand how their world views relate to the specific 'need for?'→ transformation →'need met?' process.

Figure 78: Generic Airport Process for Planes, Passengers & Their Bags

In Figure 78 the Author shows the generic Airport operating model showing left-to-right how outward bound passengers and their baggage 'flow' through the Airport to their planes and right-to-left how inward bound passengers flow through the Airport back to their point of departure. Also captured in the centre of the model is the connecting loop for passengers arriving at the Airport and transferring back out again without exiting. Also shown in Figure 78 is the flow of planes in and out of the Airport and the specific steps they take. This is argued as a generic Airport process model because this process can be found in most Airports across the UK and around the World.

For this investigation the focus is on the asset management of the 'stand' part of the generic Airport process. Reviewing the Airport process illustrated in Figure 78, the taxi to stand; on stand arrival; turn around (by ground handling agent); pre-departure processes and finally aircraft pushback all relate directly to the transformation process and make it meaningful from the affectees perspective. The stand must be available and assets operational for the airline, the airfield stand manager (who represents the Airport) and the ground handlers so they can provide a service to their customer.

Owner (O)

The owner of this transformation process with the power and overall responsibility for the performance of the system is the Airport Chief Operating

Officer (COO). The COO is the lowest level in the organisation where the transformation process can be removed. This was validated during the action case study development when the COO announced a large cut to the asset management budget due to reduced income during the forced closure of the Airport from the volcanic ash incident and severe snow earlier in the financial period.

The budget cut meant some asset management activities would be reduced, eliminated or delayed and the 'need for' asset management requirements therefore may not 'be met' as preventative maintenance activities are not completed to the original schedule. The decision to reduce the budget and to therefore take out elements of the transformation process was made by the COO confirming them as the owner of the transformation process.

Environmental constraints (E)

The internal and external constraints influencing the asset management transformation process can be listed as:

Internal

- Airport Operating Regulations (CAP168)
- Time available to complete maintenance works
- Integrity requirement
- Condition requirement
- Performance requirement

External

- Volcanic eruptions
- Weather (in this case snow forced the Airport to close)
- Economic changes

In summary the CATWOE for airfield asset management of stands has identified the customers as the airfield stand managers (who represent the business); the airlines and the ground handlers. The actors have been identified as the asset steward; facilities manager; maintenance planners; facilities team leaders and technicians all participating in the transformation process. The asset management transformation process is understood by establishing the 'need for' through the three asset management requirements quantified by the customer requirements and understanding if these 'needs have been met' by measuring the Leading and Lagging measures of asset management performance.

The worldview for the generic Airport process of operating a stand from the perspective of the affectees has been shown in Figure 78. The owner has been identified as the Chief Operating Officer with the power and overall responsibility for the asset management process. Finally, the environmental constraints have been listed and are based around the internal constraints: Airport regulations; time; the three asset management requirements and the external constraints including: volcanic eruptions; weather and economic changes.

Developing a conceptual model from the CATWOE definitions for airfield asset management, in Figure 79 the Author shows how the customers; actors; transformation process; world view; owner and environmental constraints combine to show a holistic model of the asset management process for airfield stands.

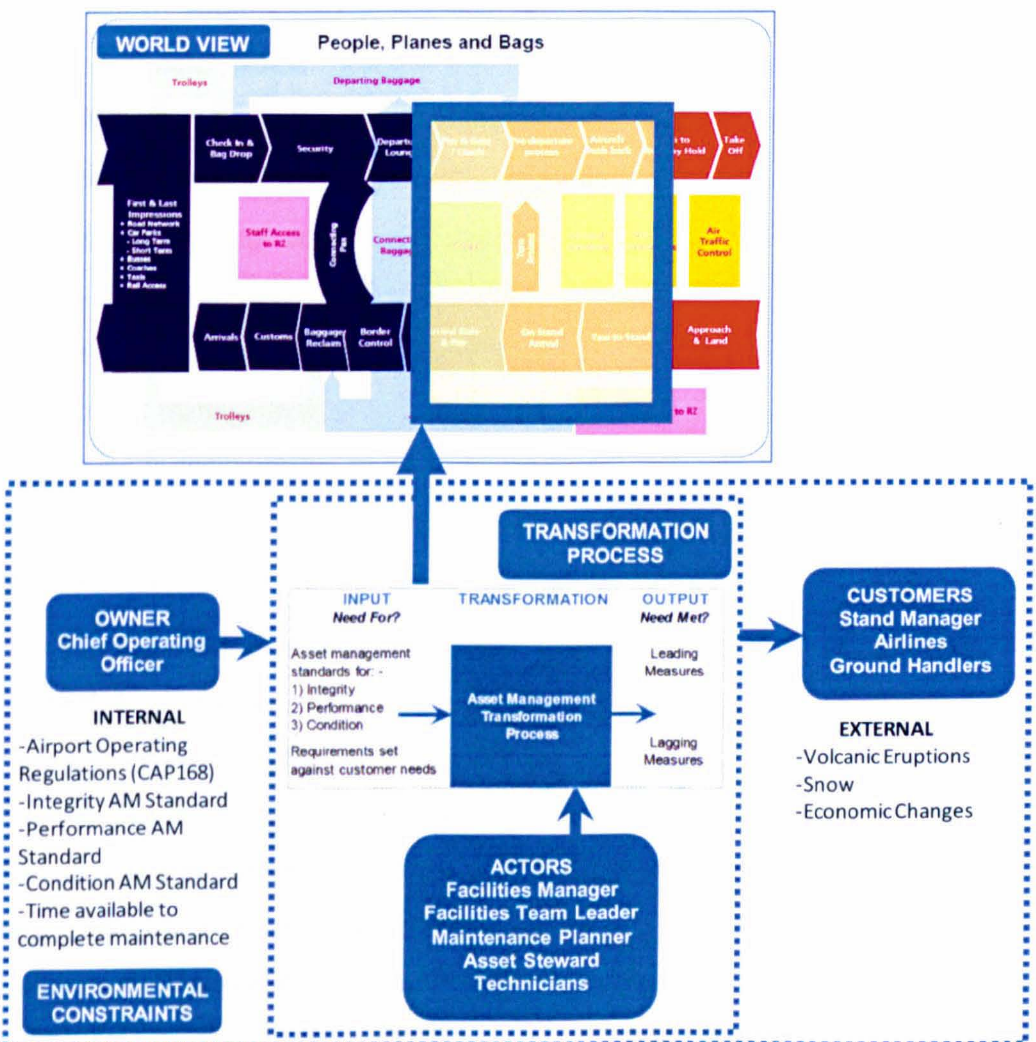

Figure 79: Conceptual Model of the Asset Management of Airport Stands

9.2.5 Value Improvement Model Implementation

The value improvement model for asset management for Airport stands has been developed and the CATWOE tool has been used to establish a conceptual model of the Transformation Process taking into account the Customers, Actors, World Views; Owner and the Environmental Constraints within the Airport. The following section describes the development of a template for historical measures (Lagging measures) of asset management of the Airport stands using the value improvement model and CATWOE models developed. Also discussed is the effectiveness of the combined value improvement model & CATWOE approach.

The previous criticisms of the historical measures for asset management effectiveness focused on the way the measures had been applied without taking into account the key stakeholders in the asset management process. This led to the measures being seen as too academic and not applicable to the real-world environment of Airport engineering and operations. With this in mind the Lagging measure template would need to be developed in conjunction with the key stakeholders in the airfield asset management process identified through the CATWOE root definition process.

Identifying the actors and their specific roles the RACI (Responsible, Accountable, Consulted & Informed) tool was used to understand which of the actors had more of a starring role in the implementation process. RACI is a commonly used tool in project management as it identifies who is responsible (R) and does a specific activity; who is accountable (A) and has overall accountability for the project; who is consulted (C) in a two way conversation and finally who is informed (I) in a one way communication (Hartman and Ashrafi, 2004).

For the stand asset management the facilities manager was seen as a key actor being both Responsible (R) and partially Accountable (A) in the RACI as they are responsible for ensuring the assets provide the correct service to the customers (more R than A). The asset steward has to be the Accountable (A) person as they are less of a doer in the transformation process but have overall accountability if things go wrong. The other actors; the facilities team leader, maintenance planner and technicians are Consulted (C) as there is two way dialogue during the transformation process. Finally the business itself is the Informed (I) as the outputs of the transformation process are communicated to them as a wider audience.

Launch Pad to Stand & Pier Lagging Measure Summaries						
BY PIER & STAND	To give an Integrity, Performance & Condition (IPC) overview of the asset/equipment portfolio by customer/location					
	Pier 1	Pier 2	Pier 3	Pier 4	Pier 5	Pier *n*
IPC Summary	Hyperlink to Pier 1 Summary	Hyperlink to Pier 2 Summary	Hyperlink to Pier 3 Summary	Hyperlink to Pier 4 Summary	Hyperlink to Pier 5 Summary	Hyperlink to Pier *n* Summary
BY ASSET GROUP	To give an Integrity, Performance & Condition (IPC) overview of the individual asset groups					
	FEGP	SEG	Fuel Hydrants	Pavements & Markings	Fresh Water Drainage	Asset *n*
IPC Summary	Hyperlink to Fixed Electrical Ground Power Summary	Hyperlink to Stand Entry Guidance Summary	Hyperlink to Fuel Hydrant Summary	Hyperlink to Pavements & Marking Summary	Hyperlink to Fresh Water Drainage Summary	Hyperlink to Asset *n* Summary

Figure 80: Lagging Measure Template for Stand Asset Management

Using the RACI approach the lagging measure template shown in Figure 80 was developed by the Author in conjunction with the key stakeholders in the asset management process with the facilities manager representing the customer and being the main actor in the process. During the development reference was continually made to the CATWOE elements and their input to the Lagging measure template[75]. The outcome of this approach was to develop the Lagging measure template to provide asset management effectiveness information by location influencing infrastructure development decisions and by asset group showing future asset management replacement requirements.

[75] This approach really helped the author in building relationships with the 'Actors' especially the facilities manager. Through the development of the airfield engineering Lagging measure template the author continually referred to the CATWOE conceptual model and whenever engaging with the 'Actors' asked what was in it for them? Understanding the requirement from their perspective, understanding their worldview was the main objective of any interaction.

Stand IPC Elements to be Covered in Review		Fixed Electrical Ground Power	Stand Entry Guidance	Fuel Hydrants	Signs	Barriers	Fod Bins	Telephones	Fire Hydrant	Saw Dust Bins	Flood Light	Storm Water Drainage	Pavement	3rd Party Assets	LV Distribution	Loading Bridges	Comments
Standard	**Measure**																
Performance	Performance (%)	Yes	Yes	NO DATA IN MAXIMO	N/A	N/A	N/A	Yes	Yes	N/A	Yes	Yes	Yes	If applicable	Yes	Yes	
Condition	Physical Condition (1-5)	Yes	Yes		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	If applicable	Yes	Yes	
Condition	Total Cost, Materials & Resource (£)	Yes	Yes		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	If applicable	Yes	Yes	See Sam Barnett for more information about airfield spend
Condition	Mean Time To Failure (days)	Yes	Yes		Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	Yes	If applicable	Yes	Yes	
Integrity	Mean Time to Health Incident (days)	N/A	N/A		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	If applicable	N/A	N/A	
Integrity	Mean Time To Safety Incident (days)	Yes	Yes		Yes	Yes	Yes	N/A	Yes	N/A	Yes	Yes	Yes	If applicable	Yes	Yes	
Integrity	Mean Time To Security Incident (days)	N/A	N/A		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	If applicable	N/A	N/A	
Integrity	Mean Time To Environmental Incident (days)	N/A	N/A		N/A	N/A	N/A	N/A	Yes	Yes	N/A	Yes	Yes	If applicable	N/A	N/A	
	Comments			Currently no tdata in Maximo					Contact Phil Rowsell Deputy Senior Fire Officer for more information					Depends what it is (building, charge point etc)		Not currently part of Airfield Engineering	

Figure 81: Airfield Stand Lagging Measures

Refining the inputs to the Lagging measure template shown in Figure 80, Figure 81 shows a matrix developed by the Author linking with the facilities manager to understand which of the asset groups (shown horizontally) would be covered in the Lagging measure assessment matched against the proposed Lagging measure (shown vertically). This exercise was worthwhile as it highlighted the assets deemed important to the facilities manager as well as the measurements that were not as important making the Lagging measurements meaningful and less academic in the eyes of the facilities manager.

9.2.6 Airfield Case Study Summary

This investigation has introduced a useful framework for the value improvement of repetitive processes using the CATWOE SSM tool. A previous attempt to implement the use of historical measures of asset management effectiveness -as part of a value improvement model for repetitive processes- had not been 100% successful within an Airport operational engineering environment.

Taking into account the more holistic approach realised through applying a soft systems methodology the CATWOE tool has been used to gain an understanding of the root definition of the problem statement developing a conceptual model used to facilitate an improvement to the implementation process.

9.3 Discussion

R7. Can the value improvement model be further developed to a more generic level moving away from the specific lean tools such as 5S and OEE by applying systems thinking?

The action case study approach applied in the airfield engineering invention presented in this Chapter has shown an important link with systems thinking and in particular the soft systems approach as proposed by Checkland (1999). The application of the CATWOE approach in-situ, to a real-world problem has validated the usefulness of this soft systems tool and helped to identify the critical factors which must be fully understood when developing a value improvement model for repetitive processes.

Reviewing the effectiveness of the joint value improvement model and CATWOE approach the value improvement model has been introduced as a new concept where previous attempts at implementation in the field of asset management highlighted the model needed some development to make it more effective. The proven CATWOE tool has shown areas of weakness in the value improvement model.

One area in particular is the identification of the actors who are instrumental in the repetitive process element of the value improvement model. Overcoming this weakness, reference to the actors and their core competences (via the development of a RACI for the repetitive process as shown in this case example) can be added to the internal influencing band of the value improvement model and a description added to supporting guidelines for using the approach.

Also missing from the value improvement model is a clear reference to the customer. Although the customer requirements are shown as an input to the repetitive process the CATWOE customer definition suggests all 'affectees' of the transformation process should be identified. Again, this could be added to the internal influencing band of the value improvement model with supporting guidelines for using the approach.

Relating to the customer and also missing from the value improvement model is the Weltanschuuang, the worldviews which make the model meaningful from the different affectee perspectives. Overcoming this weakness the world views could be shown externally to the external influences or alternatively multiple value improvement models could be developed for the different affectees and their individual world views. Either way, there should be supporting guidelines for understanding the world views of the value improvement model. Perhaps this could be an area for future research in developing the value improvement model using the soft systems methodology as proposed by Checkland (1999).

Although not critical in this case example, the identification of the owner of the value improvement model is not clear and this should be added to the internal influencing band with supporting guidelines. Finally, the environmental constraints both internal and external are not explicitly shown on the value improvement model and therefore need to be added to the relevant band. For example, the determinative external environment constraints could be added to the external influencing band of the model with supporting guidelines and prompts. Similarly the normative internal environmental constraints could be added to the internal influences band of the value improvement model.

Building on the preceding discussions in the development of a generic value improvement model for repetitive processes, also identified in the investigation was the use of 3Es: Efficacy, Efficiency and Effectiveness as a useful framework for establishing measures of the repetitive process (Checkland and Scholes, 1990). For the value improvement model these have been introduced as performance measures to be developed for the repetitive process:

- Efficacy, does the repetitive process work at a fundamental level?
- Efficiency, are the resources good at delivering the repetitive process?
- Effectiveness, is the customer (internal & external) satisfied with the outputs of the repetitive process?

The final change to the value improvement model comes from the application of 5S. During the airfield engineering and body scanner case study implementations the author realised that the main influencing factor to the repetitive process from a 5S perspective is the management of process information. The 5S can be used as a tool for managing this information but it is this information which is more important than 5S.

A good example of this relates to the airfield engineering and the requirement to keep all records in the Asset Management Centre (AMC) which is a central repository for all drawings and asset documentation. As part of the asset stewardship review of the airfield and taking into account all of the assets across the Airport, the Author developed a filing structure -using 5S principles- so that all process information could be filed.

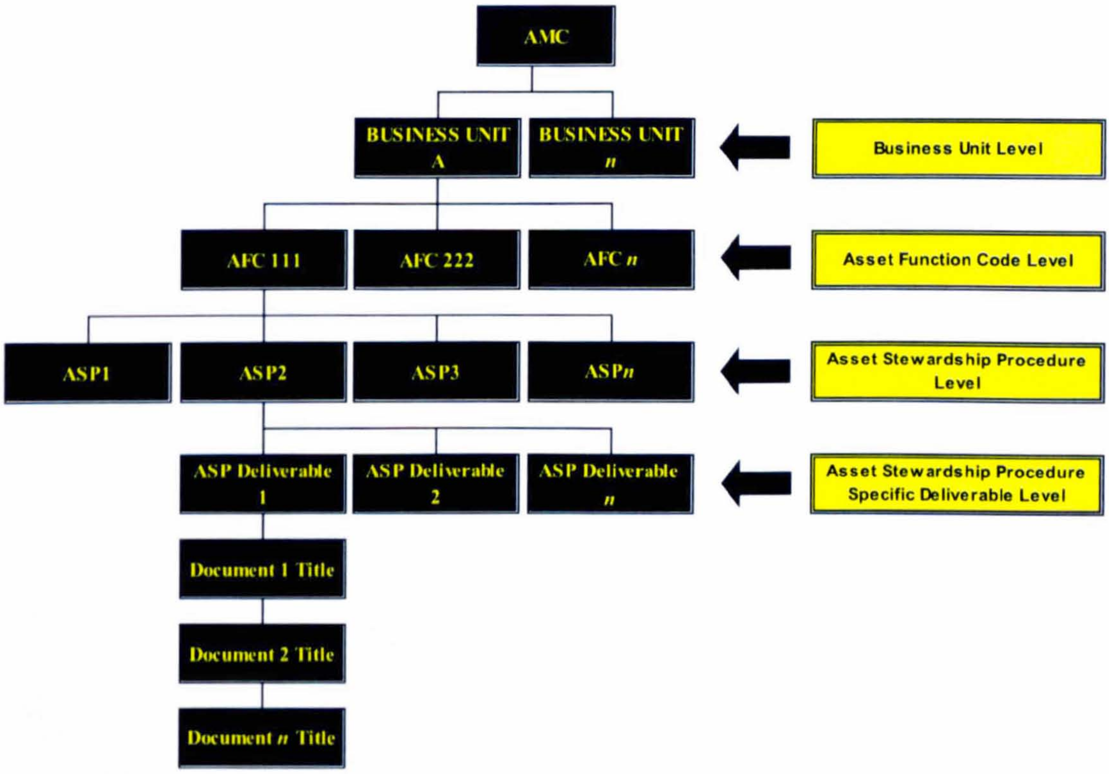

Figure 82: 5S Applied to Filing Systems for Asset Process Information

Figure 82 shows the hierarchy for filing the information which was developed and implemented by the Author. As a consequence of the success, this approach has been disseminated to other areas of the business to control process information[76]. One of the key benefits of applying 5S principles to document recovery is the speed in which documents can be retrieved. In the example presented any document, for any asset was retrievable in 10 seconds of entering the AMC folder.

[76] The author has found during this journey of theory development and practical implementation that if something is deemed to be good and useful, other people will want to use it (from a practitioner perspective). Perhaps this is an indicator of success? For example, the author developed a 'lean meeting system' out of the need to streamline the non-value adding elements of meetings such as recording attendees, date, agenda items etc during the meeting. The approach is now being used across the Airport in different departments and at a business where the author was previously employed.

As a result of the case study applications and in particular the airfield engineering review using the SSM CATWOE approach, the 1st draft value improvement model for repetitive processes presented in Figure 54 has been updated to make it more generic and less 'tool' specific. The author argues that the value improvement model provides the framework for understanding and the tools can be used for data collection &/or operationalising the value improvement model.

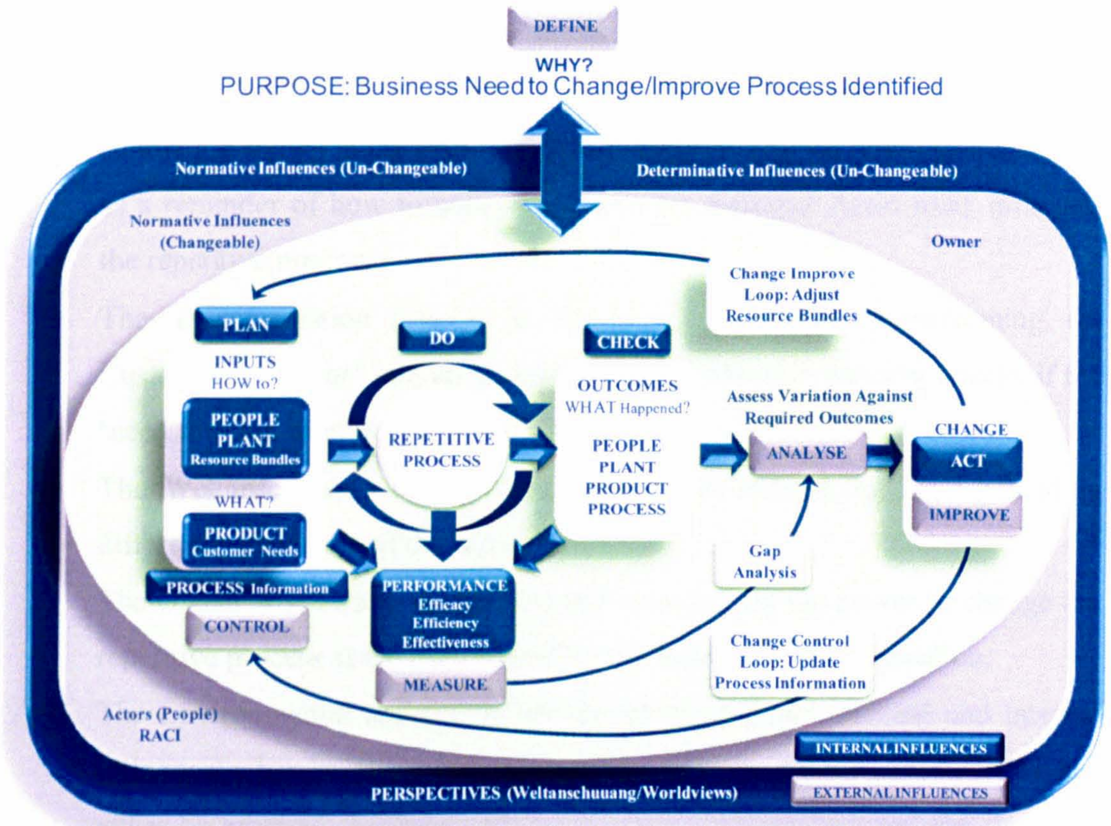

Figure 83: Generic Value Improvement Model for Repetitive Processes

Figure 83 shows the final draft of a generic value improvement model for repetitive processes as presented by the Author including the seven Ps discussed in Section 8.1: Purpose, Perspective, People, Plant, Product, Process & Performance.

- Purpose is shown externally and questions the need to change.
- Perspective now sits in the external influences band and encompasses the different views from the different affectees of the repetitive process.
- People & Plant are shown as the resource bundles providing a service to the repetitive process.
- Product is shown as the customer needs and represents the value statement for the repetitive process.

- Process information is shown as underpinning the People, Plant & Product inputs to the repetitive process.
- Performance is shown classified as the 3 Es: Efficacy, Efficiency & Effectiveness.

The CATWOE elements have also been added to the value improvement model and provide a useful framework for operationalising the model.

- Customer needs (Product) are shown as a direct input to the repetitive process.
- Actors are shown in the internal influencing band and the RACI tool is shown as a reminder of how to understand how the different Actor roles influence the repetitive process.
- The Transformation process is the repetitive process transforming the Customer 'need for' into an Outcome and the Measure element checks if the 'need for' has been 'met'.
- The Weltanschuaang is shown in the external influencing band providing different perspective of the repetitive process.
- The Owner is shown as an internal influence having the power to change the repetitive process at the lowest level in the management organisation.
- The Environmental constraints are shown in both the external and internal influencing bands. Normative Constraints are socially constructed and can either be external (unchangeable) or internal (changeable) and are therefore shown in both internal & external bands. Determinative constraints relate to the Natural World including the weather and environment and are shown in the external influencing band.

9.4 Conclusion

The use of the '7P's and CATWOE to operationalise the model should not restrict the population of the internal and external influencing bands. For example, the next section of the thesis will show how Railway Regulation sits in the external influencing factors as the Civil Aviation Authority did in the airfield engineering case study presented in the preceding section.

Chapter 10: Applying the Value Improvement Model to Management

10.1 Introduction

This Chapter of the thesis is based around a paper which has been accepted for presentation at and publication in the conference proceedings of the Third European Research Conference on Continuous Improvement & Lean Six-Sigma at Strathclyde University taking place in March 2011 (Gibbons *et al.*, 2011b). The paper introduces the concept of "current state" & "future state" value improvement models using a case study example of an Airport inter-terminal passenger transit shuttle system.

Using the generic value improvement model presented by the Author in Figure 83 a current state value improvement model will be developed for the repetitive process showing gaps in the value improvement framework for the shuttle asset management repetitive process. Complementing the current state value improvement model will be the development of a future state value improvement model for the shuttle asset management repetitive process. The gap between the current and future state models can then be closed by establishing a management value improvement model for the shuttle asset management repetitive process.

10.2 Management VIM: Inter-Terminal Shuttle Case Study

The focus of this investigation is to review the asset management of a shuttle transport system used to transfer passengers between terminals at the Airport. The system runs 24 hours a day, 7 days per week and provides a critical service to the business. Performance is measured against down-time and if the shuttle system is unavailable for a certain period of time then rebates are paid back to the customers. Also when the system is unavailable a temporary coaching system is deployed to transfer passengers between terminals.

As has been shown in the preceding case studies, a useful tool for mapping and understanding the scope of a repetitive process is the Supplier-Input-Process-Output-Customer SIPOC tool (Pyzdek, 2003). More specifically, the SIPOC tool can be used as a methodology to identify factors influencing the repetitive process which can be used to populate the value improvement model. Using the information from the SIPOC -with a specific understanding of the output(s) to the customer- the requirement from the process owner is detailed for the product being processed.

Therefore this product requirement encompasses the voice of the customer and is the value statement for the particular value improvement model. From a lean perspective this value statement can be used to identify what is value-adding (VA), non-value-adding (NVA) and necessary but non-value-adding (NNVA) (Hines and Rich, 1997; Rother and Shook, 1998; Hines *et al.*, 2000; Jones and Womack, 2003) later in the VIM improvement cycle.

The SIPOC tool is also useful for identifying the Customers, Actors, Transformation Process and World Views as part of the CATWOE approach discussed in the previous section.

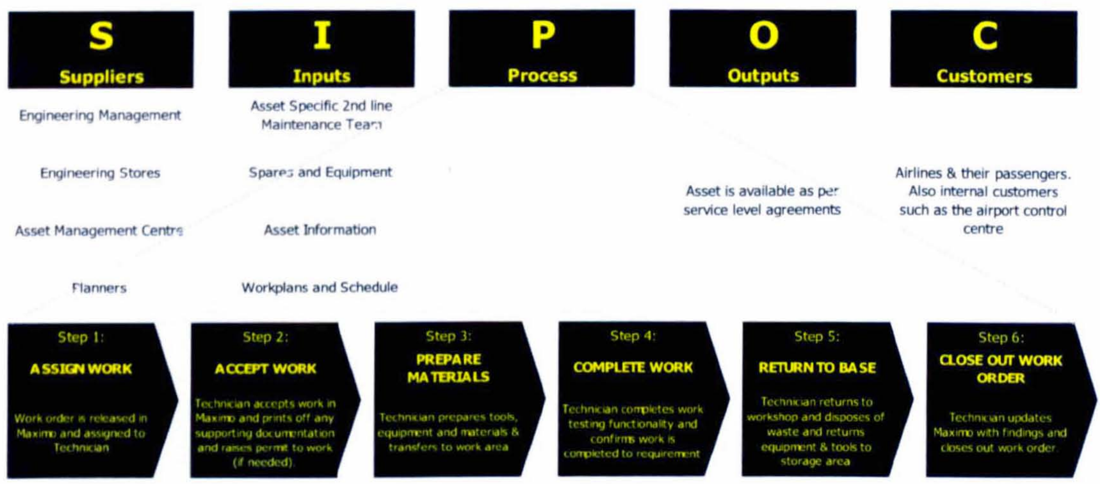

Figure 84: Process Map for Planned Maintenance

In this case study the generic value improvement model is used to first identify the current state of the repetitive process and then to develop a future state value improvement model. Developing the shuttle value improvement model, Figure 84 shows the SIPOC model for the planned maintenance repetitive process of the shuttle as proposed by the Author.

The main external customers of this process are the Airlines and their passengers, and the internal customer is the Airport Control Centre (ACC) who have control over the operation of the shuttle system. The expected output of the maintenance system is the asset availability to the agreed service level requirements. Providing a service as an input to the process are the suppliers including engineering management (resources), engineering stores (spares & equipment), asset management centre (asset information) & finally the asset planners (maintenance work plans and schedules).

Developing a current state value improvement model of the shuttle asset management repetitive process, one-to-one and group meetings with shuttle technicians and engineering managers were made taking reference to the generic value improvement model presented in Figure 83. Also the Author attended operational meetings to gain an understanding of the asset management process and a review was made of all available shuttle performance data.

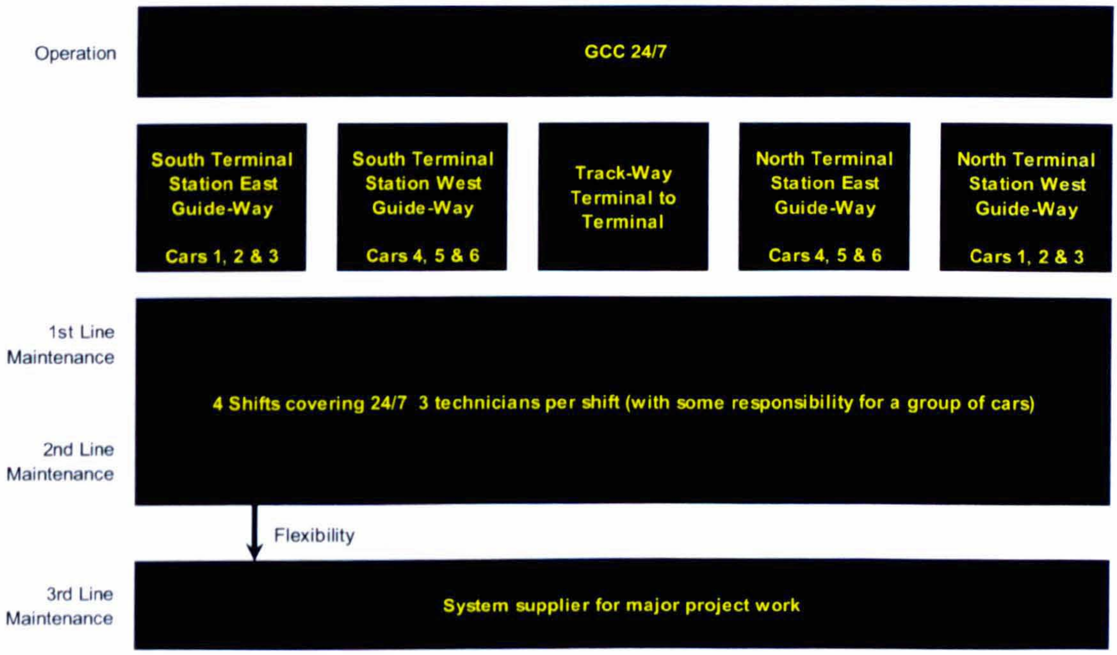

Figure 85: Shuttle Technician Lean Resource Matrix

Reviewing the 'How to?' and matching of people and plant as resource bundles providing a service to the asset management process there are 4 shift crews currently completing 1st line (unplanned) and 2nd line (planned) maintenance activities covering a 24 hour, 7 day a week period. The teams are based in a workshop beneath one of the shuttle stations with resources capable of completing major overalls of the shuttle plant.

In Figure 85 the Author shows the shuttle technician lean resource matrix indicating the shuttle technicians are horizontally flexible covering all elements of the shuttle system and vertically flexible covering 1st and 2nd line maintenance activities as well as supporting 3rd line (project) maintenance when required. Also shown is the Gatwick Control Centre (GCC), the central control point of the landside Airport Operations.

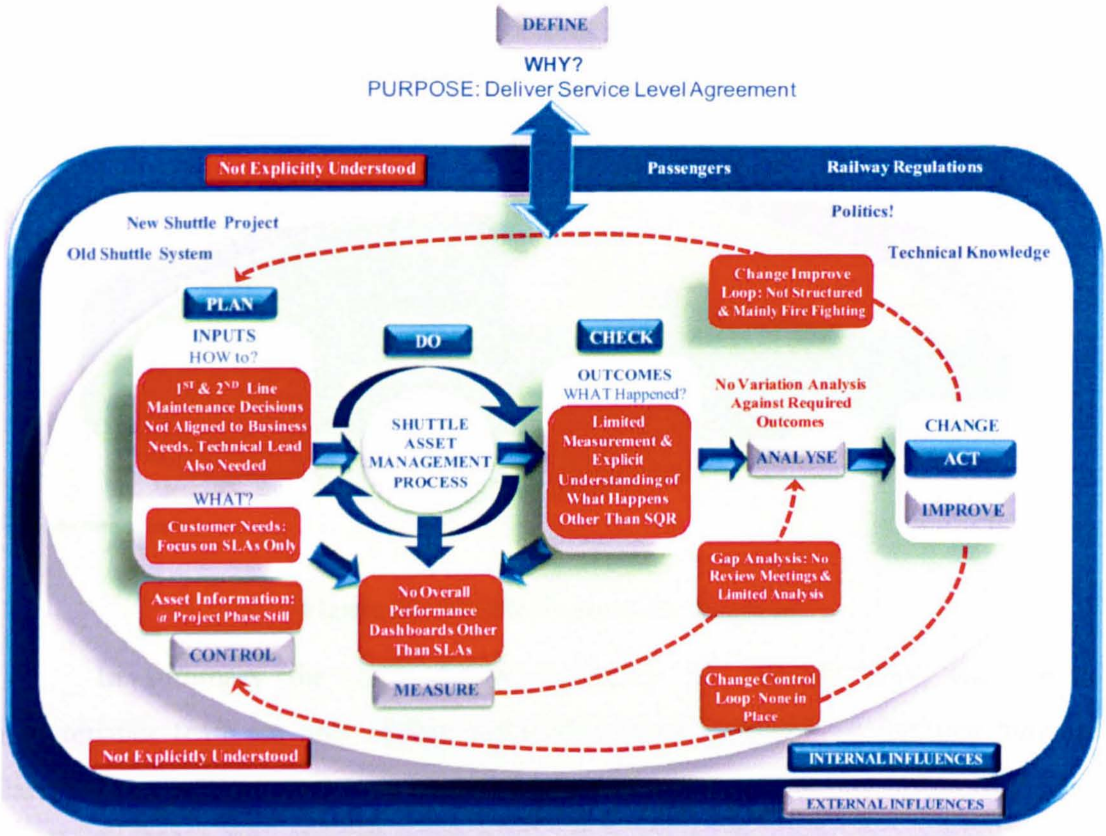

Figure 86: Current State VIM for Shuttle Asset Management

In Figure 86 the Author shows the current state value improvement model for the asset management repetitive process with the areas of concern highlighted in red. The current state value improvement model shows this as requiring improvement with regard to matching working hours to the best times to complete planned maintenance activities on the shuttle when it is taken out of service. The current shift pattern restricts the amount of hours of planned maintenance that can be carried out in non-critical periods of shuttle operation.

Figure 87 shows the Author's value analysis of the shuttle maintenance activities where the following categorisations of value were used:

- Value Add (VA): The time on the tools whether for 1st (unplanned) or 2nd line (planned) maintenance.
- Necessary but Non-Value Adding (NNVA): Activities which must be carried out in relation to planned or unplanned maintenance such as collecting materials, travelling to the site and updating the maintenance management system.

- Non-Value Add (NVA): Classified as resource contingency or time waiting for a fault.

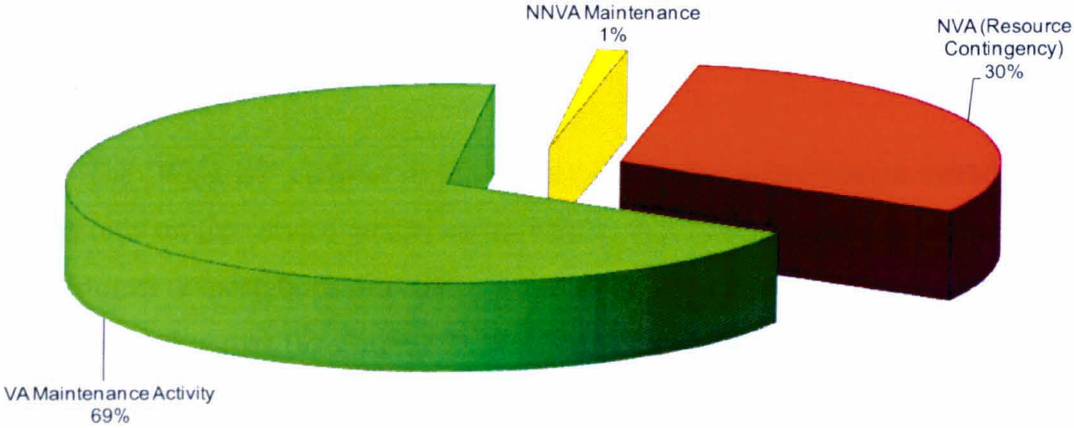

Figure 87: Shuttle Team Value Analysis

In summary the data shown in Figure 87 indicates that the Shuttle maintenance team are only adding value 69% of the time, 1% of the time they are carrying out indirect work with respect to the planned or unplanned maintenance and finally for 30% of the time they are waiting for failures to occur. To understand this further the data was broken down by the Author to the shift level, by hour as shown if Figure 88. Shifts 1 & 2 appear to have a much higher levels of non-value adding contribution in comparison to shifts 3 & 4.

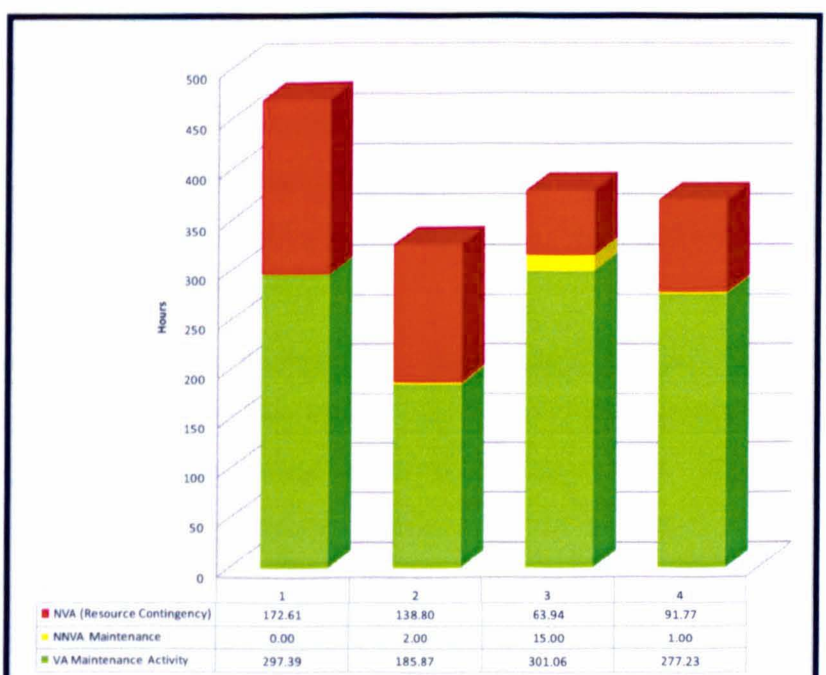

Figure 88: Shuttle Value Analysis by Shift

Another area for improvement with the resource bundles is the lack of technical knowledge at a professional engineering level with no single point of contact for technical leadership. This is linked to the technical leadership and will be discussed under internal influences and Railway Regulations will be discussed under external influences

The 'What is?' element of the current state value improvement model shows a focus only on the service quality rebate (SQR) requirements capturing only part of the customer expectations for the shuttle asset management process. The SQR system is used across the Airport to measure service levels on critical stakeholder processes such as lifts, escalators and passenger conveyors and the Airport pays rebates or receives income based on the levels of performance matched to the SQR requirements.

Supporting the 'How to?' delivering the 'What is?' are the control documentation and process information. The shuttle was recently replaced in a £47 million capital project and the process information has not been fully integrated into the information systems at the Airport. In particular there is a gap with the technical information and understanding of spare parts which perhaps can be linked to the lack of a single point of technical leadership.

Understanding the outcomes of the shuttle asset management process, the 'What happened?', the current state value improvement model shows there is not an explicit understanding of what happened with the people, plant, process and product and the focus is mainly on understanding whether or not the SQR levels were achieved. SQR levels are tracked on a daily basis and trended to predict if the monthly level will/will not be achieved.

Also impacting the shuttle asset management process are other internal influencing factors which on the current state value improvement model are shown as being not explicitly understood by the management team. Some areas already mentioned include the new shuttle system project, the old shuttle system (especially spares) and the lack of technical knowledge. There are also political issues between the new shuttle suppliers/project team and the operational asset management team.

Again, also impacting the shuttle asset management process are external influencing factors which on the current state value improvement model are also shown as not being explicitly understood by the management team. There is one particular input which is known and greatly influences the shuttle asset management process, railway regulations. However, as previously mentioned, the lack of technical leadership and single point of contact means this influencing factor is not necessarily fully understood and the consequence is a requirement to meet all railway regulations when possibly not all are applicable as the shuttle system is not actually a train and runs on inflatable tyres on a single guide-way.

Another known influencing factor is the passengers who travel on the shuttle system. They can influence the asset management process by damaging the shuttle station and carriage doors with trolleys and bags as they force entry when the shuttle doors are about to close.

The final area of concern on the current state value improvement model is the lack of analysis -other than for SQR- as well as the lack of a structured approach to continuous improvement. The Airport asset management/stewardship process requires all asset management teams to hold weekly/monthly (depending on asset criticality) 'Plan, Do, Review' (PDR) meetings to assess team and asset performance and subsequently drive improvement. The current state value improvement model shows these meetings are not taking place and there is no variation analysis against required outcomes and any improvements made to the process tend to be based around fire fighting activities to meet the SQR targets.

11.2.1 Developing a Future State Shuttle Value Improvement Model

Overcoming the concerns identified in the current state value improvement model, in Figure 89 the Author shows the future state value improvement model for the shuttle asset management repetitive process which was developed with the shuttle management team and is structured around the extant Airport asset stewardship/management process.

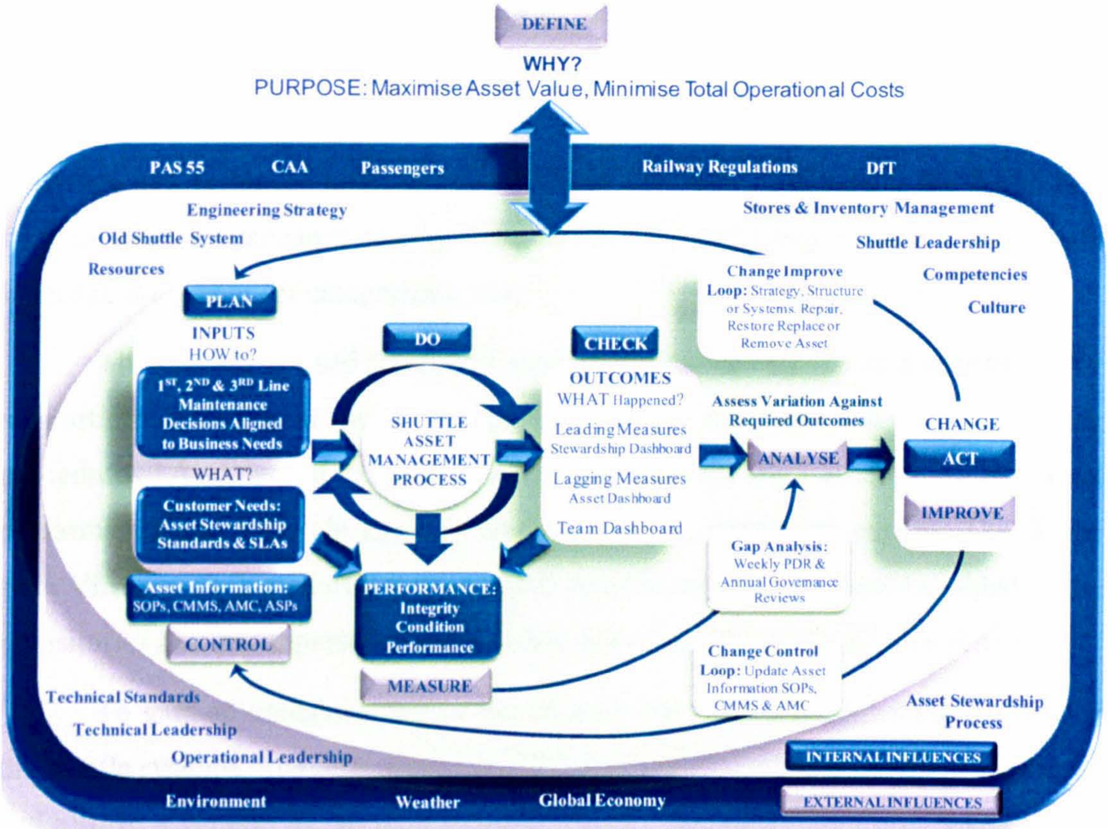

Figure 89: Future State VIM for Shuttle Asset Management

Reviewing the future state value improvement model and starting with the 'Why?' and purpose for the improvement cycle development, the justification for the asset management improvement comes from the need to balance asset governance with asset management continuous improvement. For the case study this was the first time the value improvement cycle had been used and the why statement is based around setting up the process to run the repetitive cycle to gain a base-line measurement of asset management effectiveness to drive improvement. This baseline can then be used to set future targets for value improvement cycles.

Aligning the direct inputs (the how to?) to the repetitive process the future state value improvement model shows the resource bundles must be aligned to the business needs and a change in shift pattern to support 1^{st,} 2nd & 3rd line maintenance activities is needed. Also required is a dedicated technical resource supporting the maintenance teams with railway and electrical engineering expertise.

Developing an understanding of the 'What is?' in addition to the SQR requirements there are the three previously discussed asset stewardship requirements which need to be matched to the needs of the internal and external customers.

Supporting the 'How to?' delivering the 'What is?' is the process information and systems which are made up of two areas. The first is a dedicated team who control an 'Asset Management Centre' (AMC) which is the repository for all drawings and technical information related to the asset. Supporting the AMC is a computerised maintenance management system (CMMS) based around a common language document for categorising assets.

The CMMS is used to control maintenance activities and is a repository for supporting information such as method statements and standard operating procedures. Also stored on the CMMS is historical data relating to the asset performance and lifecycle such as breakdowns and corrective repairs. The future state VIM shows that all of the new shuttle process information must be added to the repositories and any superseded information from the old shuttle must be removed.

To gain an understanding of the internal and external influencing factors for the shuttle systems reference was made back to the SIPOC model shown in Figure 84 and also to a generic model of Airport operation. Questions were also asked of the management team and technicians over what positively and negatively influences the shuttle asset management process.

Internal influencing factors found from this approach were the engineering strategy, stores & inventory management (SIM) system, core competencies, Airport culture, general leadership, technical leadership, technical standards, maintenance resources and the old shuttle system. With an understanding of the influencing factors and starting the development of the improvement cycle element in the value improvement model, some of the impacting factors such as stores and inventory management and old shuttle system were looked at in more detail to identify how their influence can be managed appropriately to provide a positive impact on the shuttle value improvement model.

For example, the SIM team provide a service where they are ensuring spare parts and materials are available as specified by the shuttle team. In the future state value improvement model this performance against this service should be measured and any gaps identified and closed out.

External influencing factors found included the weather, business strategy, environment, CAA[77], Railway Regulations, PAS 55[78], Passengers & the Dft. As previously discussed, all of these factors can have a negative and/or positive influence over the shuttle asset management process and therefore understanding their individual influences is important when developing the future state value improvement model.

For example, the Railway Regulations have already been mentioned and the shuttle team have no control over these regulations but they positively and perhaps negatively influence the process. Positively influencing by providing guidelines of how the shuttle should be operated and maintained and negatively influencing by perhaps being not totally applicable to the shuttle system which is not a train and therefore some requirements may not be necessary for the safe operation and maintenance of the shuttle system.

Developing the measure, analyse and improve elements of the future state shuttle value improvement model, outcomes of the process should be measured against three specific areas matched to the three asset stewardship standards of integrity, condition and performance as discussed in the airfield engineering case study:

1. Leading measures
2. Lagging measures
3. Team dashboards

The final element developing the future state shuttle value improvement model is to analyse the outcomes against the requirements and change the inputs and controls (if needed) to drive the value improvement. For the shuttle future state value improvement model this can be carried out via a weekly Plan, Do, Review (PDR) improvement meeting where the team dashboard is reviewed and also via an annual asset review meeting where the Lagging and Leading measures are reviewed in more detail.

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[77] Civil Aviation Authority is the UK's specialist aviation regulator.

[78] Publicly Available Specification number 55 is an asset management approach presented by the Institute of Asset Management based around optimising asset performance.

Outcomes of the annual meeting determine the plans and actions for the year ahead as well as the updates required to the asset replacement plan. The annual review is held with the asset steward who must sign off and approve the current state of the asset for Condition, Integrity and Performance. At the formal review actions are agreed based around removing, restoring, repairing or replacing the asset as well making changes to the way the asset can be maintained through the asset management system, strategy and organisation. Controlling any changes to the repetitive process inputs is a key element and any process information such as standard operating procedures and method statements must be updated to reflect any changes to the asset management processes.

10.3 Discussion

R8. Can the generic value improvement model be further developed to incorporate a current state map and future state map of the repetitive process under review?

The preceding discussion has introduced the concept of a '*current state value improvement model*' providing both a visual and descriptive image of the extant problems with the Shuttle asset management system. Looking to overcome these problems '*a future state value improvement model*' was developed providing a visual and descriptive image of the future expectations of the Shuttle asset management system. Comparing the current and future state models, the gap between the required and actual can be translated into the development of improvement objectives.

This approach is the same as that suggested by Jones and Womack (2003) who argue the realization of a future state value stream map in one big leap is not ideal and therefore suggest the use of an ideal state map as the end goal utilising future state maps as incremental leaps. The development of the ideal state map can be broken down into manageable steps employing yearly value stream plans (Jones and Womack, 2003) incorporating manageable segments of future state maps known as loops (Rother and Shook, 1998).

The concept of loops is also linked to systems thinking where loops can either feedback or feed-forward to create learning (Godfrey, 2010). Applying the VSM implementation techniques to the proposed value improvement model framework seems logical and applicable. The future state VIM is in essence the ideal state VIM and an implementation plan using the current state VIM and the improvement objectives provides the framework for a value improvement plan.

The following list summarises the changes required to achieve the future state value improvement model as presented by the Author in Figure 89: -

1. Firstly, the current state map showed an opportunity to better align the resource bundles of people and plant to match both the internal and external customer expectations. The current state map also showed a potential area of weakness with the local technical leadership in particular the requirement to have a single point of contact in relation to railway regulations.
2. Secondly, the current state value improvement model showed a lack of understanding to the internal and external customer requirements with a focus on achieving the service quality rebate targets only. The future state value improvement model shows how this must change to understand the asset stewardship requirements capturing the voice of the internal and external customers of the shuttle system in addition to the SQR expectations.
3. The third area of improvement identified in the current state value improvement model is the process information supporting the shuttle asset management process. The introduction of a new shuttle system has left the information systems 'in limbo' with a lack of clarity of process information such as spare parts and technical reference material. The future state value improvement model requires all process information for the new system are captured within the asset management centre and computerised maintenance management system and all superseded information from the old system is removed.
4. The fourth area of improvement in the shuttle system is the requirement to better understand the outcomes of the shuttle asset management process measuring performance against the asset stewardship standards creating dashboards of Leading and Lagging measures and team performance.
5. The fifth area of improvement identified in the current state value improvement model is the lack of analysis driving improvements. The future state value improvement model shows the requirement to introduce weekly plan, do and review meetings of the performance dashboards analysing gaps to identify improvements to be fed back in the process inputs.

6. The final area of concern identified in the current state value improvement model relates to the internal and external influencing factors where there is not an explicit understanding of their positive and/or negative impacts to the process. The future state value improvement model shows that a better understanding of these factors in particular the stores and inventory management, new shuttle system project hand-over and technical leadership to be better understood and perhaps in the short-term included in the weekly plan, do and review process.

Shuttle Future State Value Improvement Implementation

To facilitate the improvements required the Plan→Do→Review (PDR) meeting process was established and a meeting purpose and agenda was agreed with the shuttle engineering management team and the team agreed to meet weekly to review progress against plan. Also a vision for the shuttle system was agreed and a benchmarking relationship was set-up with the shuttle systems supplier. The team vision was to make the Airport shuttle system the most reliable shuttle in the World.[79]

Figure 90 shows an extract of the PDR meeting template developed by the Author showing the meeting purpose, required attendees, agenda, key point and actions. Due to the problems with the new shuttle system integration agenda items 3a and 3b were added to the meeting to manage the final stages of the integration process. Agenda item 3a was added to manage the final 'snagging'[80] list with the objective of agreeing what items were outstanding and when these would be complete against plan. Agenda item 3b was added to manage the integration of spare parts for the shuttle system with the objective of understanding what parts have been added to the SIM system and what parts were waiting so this could be tracked against an agreed plan.

[79] Although not discussed in detail this was seen as a way of motivating the team including the technicians who were very proud of the Shuttle system and this would give them something to aim for. The Shuttle system supplier was contacted and agreed to share performance data of systems they had supplied and had access to the reliability data thereof.

[80] Snagging in this instance is a term used to describe the small jobs required to finish of the new shuttle system integration.

SHUTTLE ENGINEERING TEAM: PLAN DO REVIEW MEETING

Meeting Purpose

Our meeting purpose is to review performance against our plan and to identify improvement opportunities which will be delivered through our actions

TEAM MEMBERS & ATTENDANCE LOG **MEETING DATE:** 02 November 2010

Required Attendees									Occasional Attendees				
Eddie Mullaly	Ian Bird	Jeff Greene	Ian Butler	Damien Wells	Duncan Taylor	Paul Gibbons			Chris Woodroofe				

Agenda

Item 1 Review **Health & Safety** Incidents in the last week (Eddie Mullallly)
Item 2 Review **Open Action Times** (Eddie Mullally)
Item 3a Review **Project Integration** outstanding snagging items (Damien Wells)
Item 3b Review **Project Integration** spare parts (Ian Butler)
Item 4 Review of **Planned work** dashboard items (PMs, SIs etc) (Duncan Taylor)
Item 5 Review of **Asset performance** dashboard items (Availability, Performance, Integrity) (Duncan Taylor).
Item 6 Review of **Team** dashboard items (MTTS, MCRT, MTTR) (Duncan Talyor)
Item 7 Review of **Most Reliable Shuttle in The World** Project (Paul Gibbons)
Item 8 Round the table and close (Eddie Mullallly)

Key Points

Project integration and stores included in weekly agenda until project has been fully handed over and all snags have been closed

Actions

WHEN Assigned	WHAT is the action required?	WHO will complete it?	WHEN to be completed
02-Nov	Review process for managing imprort/export of spares. Link up with stores management team.	Paul	09-Nov
02-Nov	Set-up weekly PDR meeting going forward	Eddie	09-Nov
02-Nov	Set-up Bombardier service feedback meeting as part of Wolfgang Postler visit.	Paul	16-Nov

Next Meeting Date: 09-Nov-10

Figure 90: Shuttle Team PDR Meeting

As part of developing a performance dashboard to be reviewed at the PDR meeting, the author completed an asset management review of the shuttle system performance developing a dashboard of performance measures. Table 19 shows the asset dashboard developed by the Author in numerical format with both the shuttle system West and East guide-ways performance shown separately and the system performance shown based on the either one or both of the guide-ways working. Also added is an indicator of six-sigma capability based on the availability percentage.

West Guideway Performance	Jan 09	Feb-09	Mar-09	Apr-09	May-09	Jun-09	Jul-09	Aug-09	Jul-10	Aug-10	Sep-10	Oct-10	Nov-10	Dec-10
Total Down Time (Minutes)	1275	1520	1265	1482	550	633	878	676	1422	743	1386	96	567	5690
Number of Faults	26	34	21	32	35	27	26	19	26	19	17	10	27	26
Mean Time To Repair (MTTR) Minutes	49	45	60	46	16	23	34	36	55	39	82	10	21	219
Mean Time To Failure (MTTF) Minutes	1668	1141	2065	1304	1260	1577	1683	2314	1662	2310	2460	4454	1579	1498
Mean Time Between Failures (MTBF) Minutes	1717	1186	2126	1350	1275	1600	1717	2349	1717	2349	2541	4464	1600	1717
Availability	97.14%	96.23%	97.17%	96.57%	98.77%	98.53%	98.03%	98.49%	96.81%	98.34%	96.79%	99.78%	98.69%	87.25%
Un-Availability	2.86%	3.77%	2.83%	3.43%	1.23%	1.47%	1.97%	1.51%	3.19%	1.66%	3.21%	0.22%	1.31%	12.75%

East Guideway Performance	Jan 09	Feb-09	Mar-09	Apr-09	May-09	Jun-09	Jul-09	Aug-09	Jul-10	Aug-10	Sep-10	Oct-10	Nov-10	Dec-10
Total Down Time (Minutes)	254	2212	1739	1730	422	759	524	892	3787	389	131	70	588	4161
Number of Faults	14	38	26	20	21	24	22	16	40	17	13	6	14	21
Mean Time To Repair (MTTR) Minutes	18	58	67	87	20	32	24	56	95	23	10	12	42	198
Mean Time To Failure (MTTF) Minutes	3170	1003	1650	2074	2106	1768	2005	2734	1021	2603	3313	7428	3044	1928
Mean Time Between Failures (MTBF) Minutes	3189	1061	1717	2160	2126	1800	2029	2790	1116	2626	3323	7440	3086	2126
Availability	99.43%	94.51%	96.10%	96.00%	99.05%	98.24%	98.83%	98.00%	91.52%	99.13%	99.70%	99.84%	98.64%	90.68%
Un-Availability	0.57%	5.49%	3.90%	4.00%	0.95%	1.76%	1.17%	2.00%	8.48%	0.87%	0.30%	0.16%	1.36%	9.32%

System Performance	Jan 09	Feb-09	Mar-09	Apr-09	May-09	Jun-09	Jul-09	Aug-09	Jul-10	Aug-10	Sep-10	Oct-10	Nov-10	Dec-10
System Performance (2 Shuttles Running)	96.59%	90.95%	93.38%	92.70%	97.83%	96.80%	96.88%	96.52%	88.60%	97.48%	96.50%	99.63%	97.34%	79.12%
System Sigma Level (2 Shuttles Running)	3.3	3	3	2.9	3.5	3.2	3.3	3.3	2.7	3.5	3.3	4.2	3.4	2.3
System Performance (1 Shuttle Running)	99.98%	99.79%	99.89%	99.86%	99.99%	99.97%	99.98%	99.97%	99.73%	99.99%	99.99%	100.00%	99.98%	98.81%
System Sigma Level (1 Shuttle Running)	5.2	4	4.5	4.5	5.3	4.9	5	5	4.3	5.2	5.3	6	5.1	3.8

Table 19: Shuttle System Asset Performance

Of importance to this investigation is the shuttle reliability which the Author presents in Figure 91 including the performance analysis as a comparison between the old and new shuttle systems. The old system was taken out of service at the end of August 2009 and the new system came into service in July 2010.

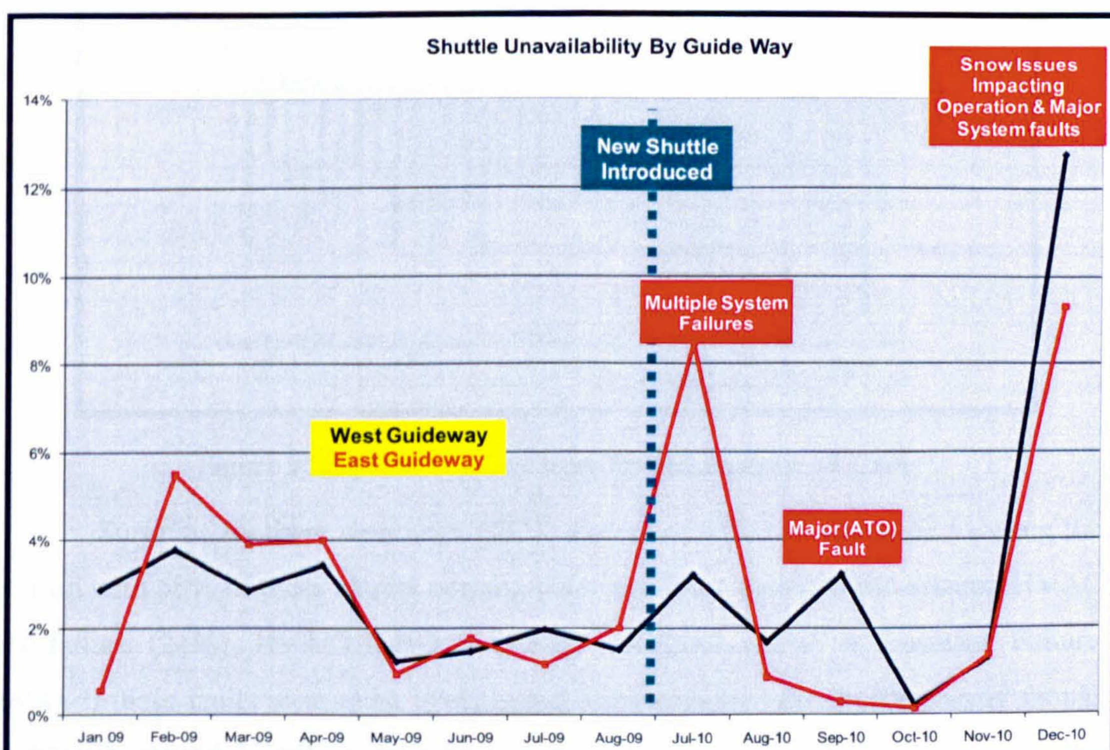

Figure 91: Shuttle Unavailability % by Guide-Way

Reviewing the unavailability data shown in Figure 91 the data shows an unpredictable system where after an initial running-in period the shuttle system achieved reasonable levels of unavailability but during September a major fault occurred impacting the unavailability figures. During October the shuttle system achieved its best performance even against the old system but then in November the system performance deteriorated before in December the system had its worst month due to a combination of bad weather and system faults. In summary the shuttle system performance is currently unpredictable and needs to be improved to match the business and customer expectations.

Seeking to understand the scale of the reliability issue the author interrogated the shuttle alarm system data which is automatically generated when a fault occurs and can be downloaded easily from the shuttle computer system. In Figure 92 the Author shows the Pareto analysis of all alarms recorded on the Shuttle system during December 2010.

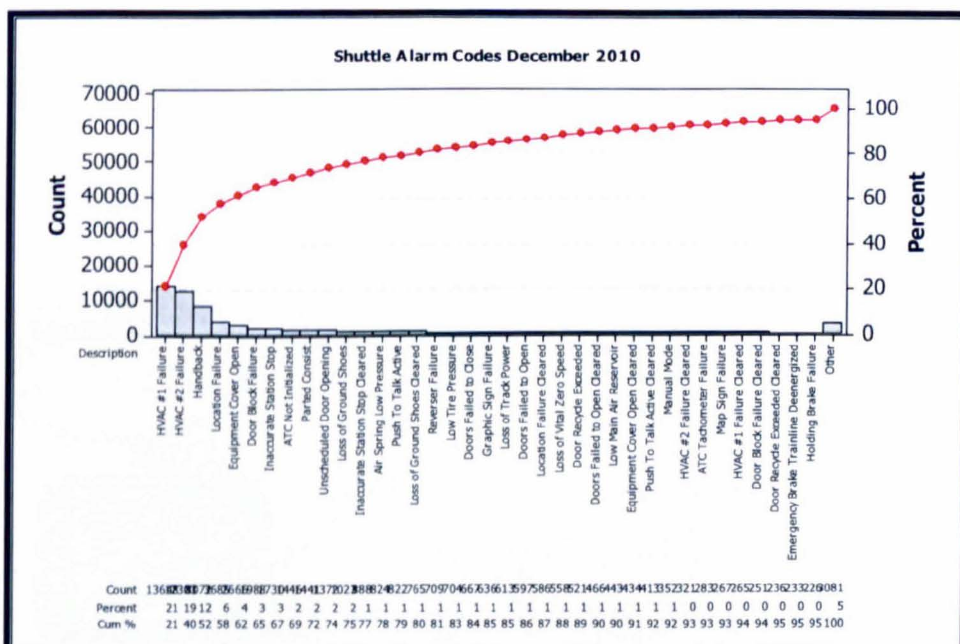

Figure 92: Shuttle Alarm Codes Pareto Analysis all Cars

Surprisingly there were over 66000 alarms recorded on the system during the period with 58% of these alarms coming from just fours faults on the system, HVAC #1 failure (21%), HVAC#2 failure (19%), Handback (12%) & Location Failure (6%). If these faults were to be investigated and eliminated the shuttle alarms should reduce to around 27700 alarms which is still significant amount and would need to be investigated further. Appendix C shows the full Pareto analysis for the individual cars as completed by the Author.

The Pareto analysis has shown how the measure, analyse and improve elements of the value improvement model are critical to improving the repetitive process. Continuing with the implementation of the improvements the following analysis was carried out in parallel to the alarm and unavailability investigations.

Through weekly one-to-one meetings with the Shuttle Engineering Manager the author developed a good working relationship and got to understand the problems the manager faced. Right from the start the author could see how stretched/stressed the Shuttle Engineering Manager was and found through the discussions that he was also responsible for another large group of assets. In parallel to managing the shuttle system, the manager was also responsible for maintaining the whole of the Airport transport vehicles including all of the airfield vehicles such as snow ploughs, off road vehicles and, road sweepers. This meant the Engineering Manager had to split his time 50-50 between the two roles and did not have enough time to manage the shuttle system as he wanted.

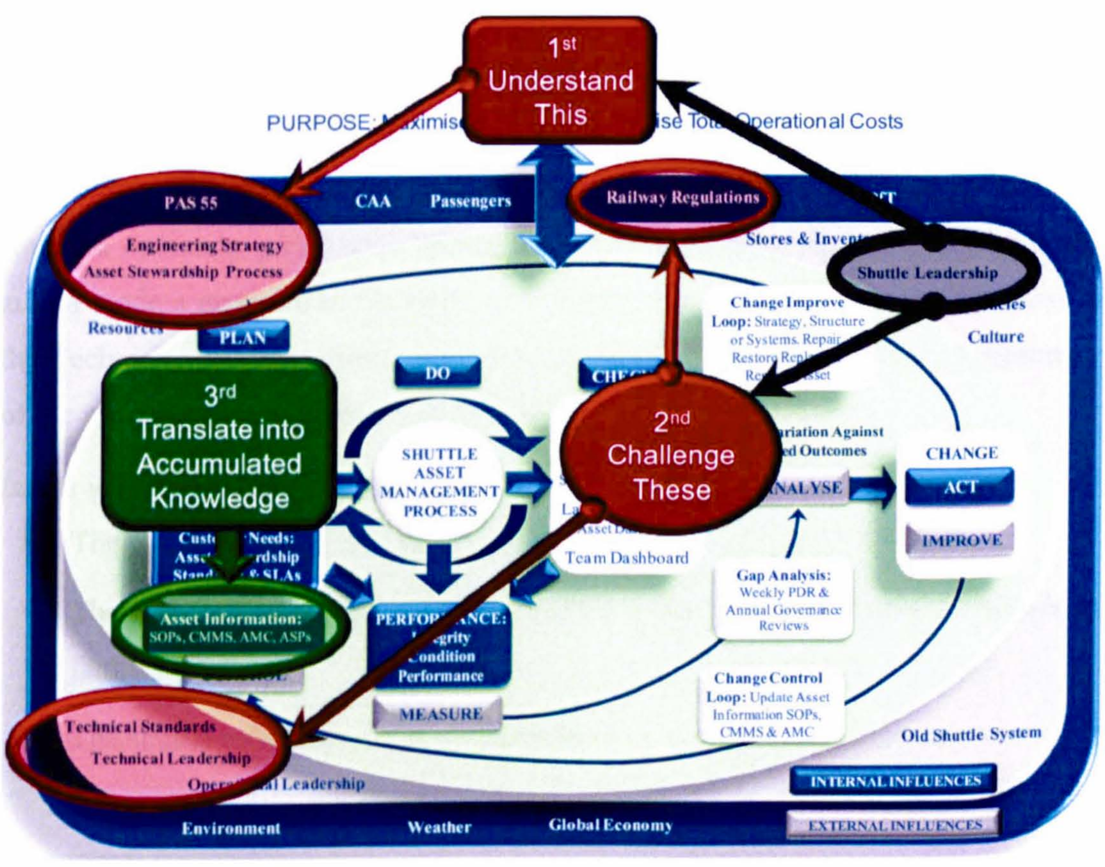

Figure 93: Leadership Link to Engineering & Technical Management

Referring to the future state value improvement model, in Figure 93 the Author shows the link between the shuttle engineering management role and the need for a technical specialist through the internal influencing factors: leadership, engineering strategy, technical leadership and technical standards as well as the external influencing factor: Railway Regulations. As part of the improvement project the Shuttle Engineering Manager proposed the recruitment of a technical support resource to both deputise in a leadership role as well as be a single point of contact from a technical perspective.

The proposal to recruit a Deputy Engineering Manager and Technical Specialist was not accepted by the process owner[81]. However, the decision was made to split the Shuttle and Transport Engineering Manager role up and recruit a second Engineering Manager to manage either of the asset groups leaving the existing Engineering Manager the choice of which asset group he wanted to manage. On this basis the manager decide to focus his efforts on the motor transport teams leaving a vacancy for a Shuttle Engineering Manager.

With reference to Figure 93, the author found this an excellent opportunity to change the role of the Shuttle Engineering Manager. The role would encompass both the management of the team and a technical role where the new manager would have to understand the internal engineering strategy, challenge the external Railway Regulations, challenge the technical leadership and standards and translate this into standard operating procedures for the shuttle asset management. On this basis the author made a proposal to the Head of Engineering using the evidence presented in the Technician value analysis, unavailability and alarm Pareto analysis. A summary of the presentation key points is as follows:-

Issues with current state Shuttle

- There is no single point of contact for day-to-day technical leadership.
- There is limited to no root cause analysis carried out or trending analysis of faults.
- The shuttle reliability is not predictable.

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[81] This is with reference to the CATWOE use of the term owner. In this instance the owner with the power to change the system at the lowest level of the organisation was the Chief Operating Officer

- Shuttle Technicians on average are only adding value (tool time) 69% of the time.
- In December there were still >66000 recorded alarms on the new system, six months after it was introduced.
- The spare parts for the new system have not been chosen systematically and there is currently a weakness in the system where we may have a stock-out of a critical part.
- SQR data collection is manual and would benefit from using the alarm system to record system outages (as per alarm Pareto).

Role Profile & Shuttle Improvement Opportunities

- Incorporate a higher level of railway and electrical safety skills and experience into the role profile.
- This would need to be matched to a systematic approach to problem solving as either a certified lean six-sigma green in a similar environment.
- Also look at the business requirements/expectations of the shuttle; review the engineering strategy and challenge the internal technical standards and the external railway regulations and translate this into a revised schedule of maintenance activities.
- Candidate would also need to have strong change management skills and experience gained in a unionised environment to implement the changes to people, process and plant performance.
- Also would be useful for the candidate to have previous exposure to stores and inventory management systems in particular balancing the costs of storage to the costs of failure and lead times. Minimal stock, maximum value.

The proposal to change the role profile was accepted by the Head of Engineering and the author was asked to update the existing role profile with the relevant changes discussed. Also, in line with the concepts discussed in this thesis the author has requested that the Lean Recruitment Framework be used as part of the recruitment process.

10.4 Conclusion

This section of the thesis has introduced the use of a management value improvement model developing current state and future state value improvement models for the repetitive process. The conceptual framework presented has been operationalised and tested on a case study based around improving the asset management effectiveness of an inter-terminal shuttle system.

With reference to the current state and future state value improvement models, the Plan→Do→Review process was established and a draft measurement framework established. Analysis of the measurements led to the identification of both technical issues with plant reliability and leadership problems with the Engineering Manager stretched between two large asset portfolios. Through the implementation of corrective actions identified in the value improvement models, these issues are now being rectified and in the future, the shuttle system will see the benefits of these improvements.

The next section of the thesis will show other examples of the value improvement model application to other repetitive processes including stores & inventory management and Airport sustainability.

Chapter 11: Other Value Improvement Model Applications

11.1 Introduction

This Chapter includes two other applications of the value improvement model to provide evidence of how generic the model has now become. The first example is a case study of a stores and inventory management system providing operational and engineering consumables and spares across the Airport. The second example shows how the value improvement model can be applied to delivering an environmental strategy, based around a 10-year plan (Gibbons and Attwood, 2011)

The purpose of this section is to provide a brief overview of the model examples and not to discuss the case studies in detail.

11.2 Value Improvement Model for Stores & Inventory Management

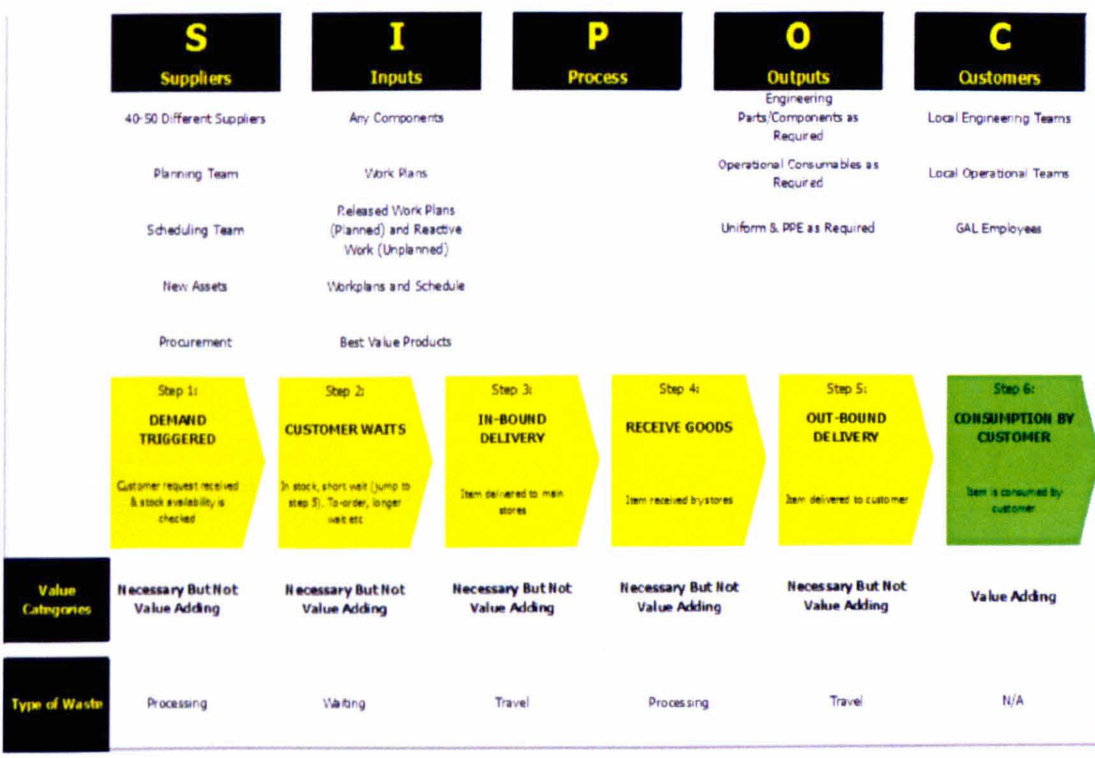

Figure 94: SIM SIPOC

In Figure 94 the author shows the SIPOC model developed for the Stores & Inventory Management (SIM) repetitive process at the Airport. Through the SIPOC model it was possible to identify the 3 main customers and subsequently the lower level repetitive processes to be developed for the SIM team:

1. Engineering teams and the asset specific spares
2. Operational teams and the consumables they require

3. Airport employees and their uniform and PPE requirements

Similarly to the shuttle case study example, the author developed a working relationship with the SIM Manager and met on a weekly basis and also attended team meetings. The outputs of these observations and discussions with the SIM Manager led to the development of a current state value improvement model for the SIM repetitive process.

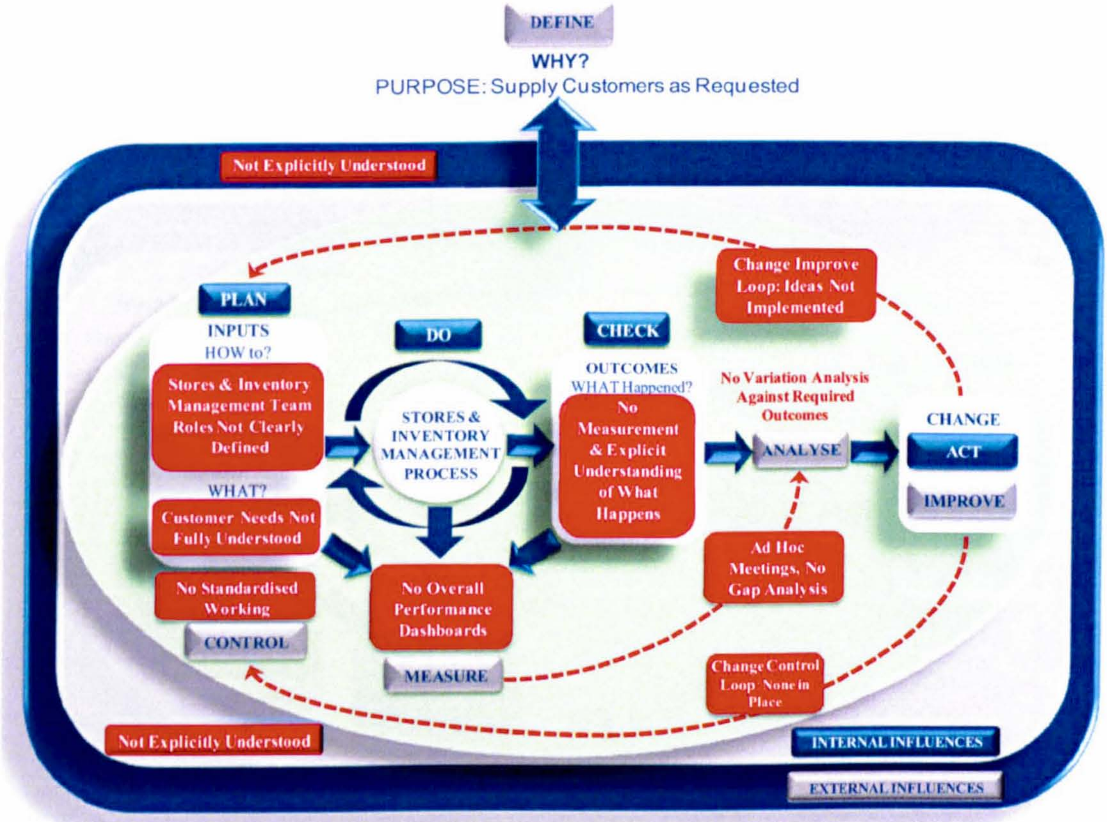

Figure 95: SIM Current State Value Improvement Model

In Figure 95 the Author shows the current state value improvement model for the SIM repetitive process. The following bullet points summarise the problems identified with the SIM repetitive process through using this model:-

- Resource roles are not clearly defined
- Customer requirements are not fully understood
- There is no standard working within the repetitive process
- There is no measurement or explicit understanding of what happens
- There are no performance dashboards
- There is no gap analysis and team meetings are ad hoc

- Ideas are being suggested by the stores personnel but not being implemented by the management team.
- There is no change control loop in place
- Internal and external influencing factors are not explicitly understood.

Understanding the expectations of the SIM Manager, Figure 96 shows the future state value improvement model for the repetitive process developed by the Author.

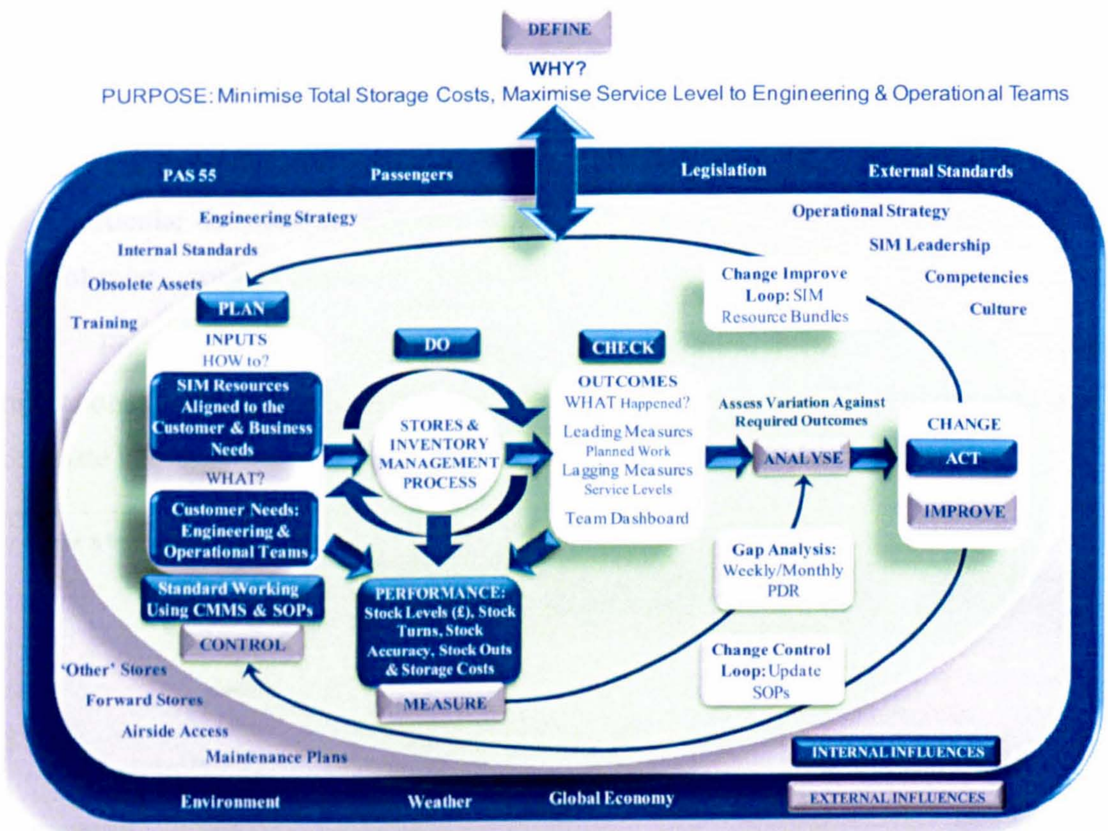

Figure 96: SIM Future State Value Improvement Model

The following bullet points summarise the requirements to achieve the future state SIM value improvement model:

- Resource roles and activities must be defined more clearly
- The expectations of the two main customers must be understood
- Standard operating procedures must be developed for the repetitive processes and the Computerised Maintenance Management System (Maximo) should be utilised for managing stock.

- Team Dashboards, Leading measure and Lagging measures must be developed based around five fundamental measures of Efficacy, Efficiency and Effectiveness:
    1. Stock Outs
    2. Stock levels (£)
    3. Stock Turns
    4. Stock Accuracy
    5. Storage Costs (£)
- A weekly Plan→ Do→Review meeting must be established to complete the gap analysis and improve/control cycle.
- Internal and External influencing factors identified must be better understood in particular the need for forward stores around the Airport and the management of obsolete stock as assets are replaced across the Airport.

Finally, in Figure 97 the Author shows the lower level SIPOC model for the operational consumables repetitive process. Also added to the SIPOC are categories of waste and improvement suggestions made by the stores personnel.

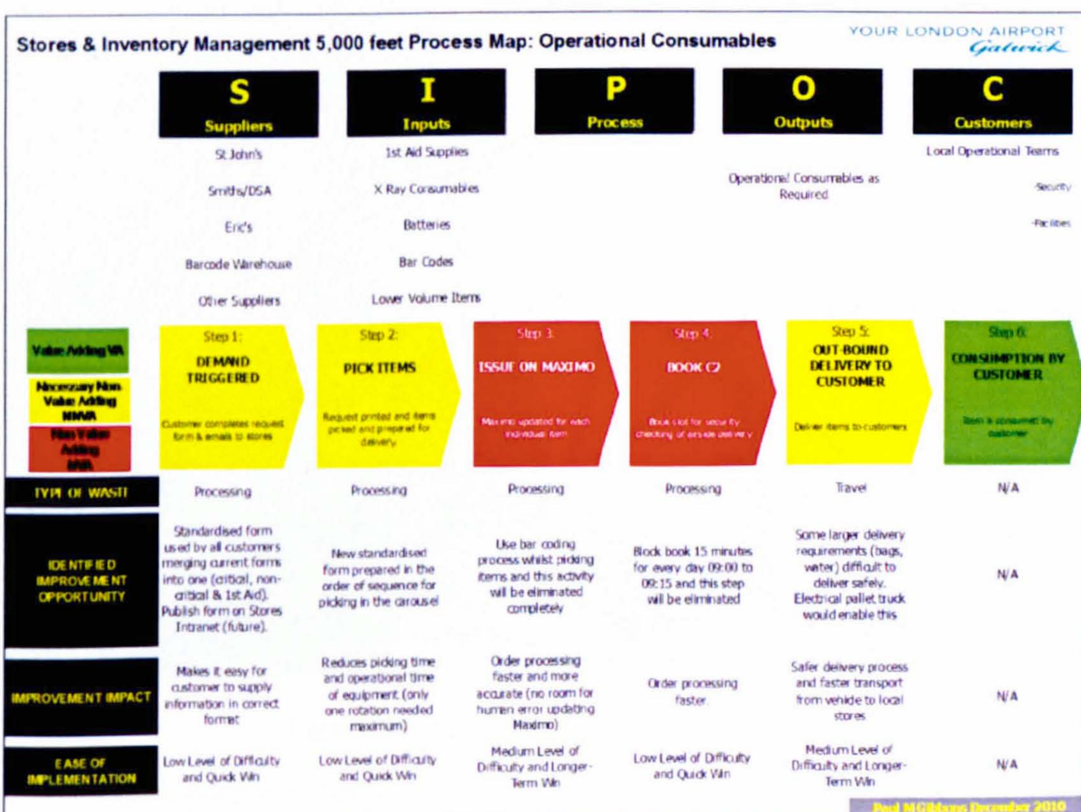

Figure 97: SIM Operational Consumables SIPOC

Figure 97 and the improvement suggestions made by the team shows that there are quantifiable and achievable improvements to the SIM process which could be implemented.

11.3 Value Improvement Model for Environmentally Sustainable Airport

Figure 98 shows the Airport environment strategy encompassing a 10 year plan to tackle 7 major issues impacting the environmental sustainability of the Airport encompassing:

1. Carbon Emissions
2. Air Quality
3. Noise
4. Energy & Water
5. Waste
6. Surface Water & Drainage
7. Biodiversity

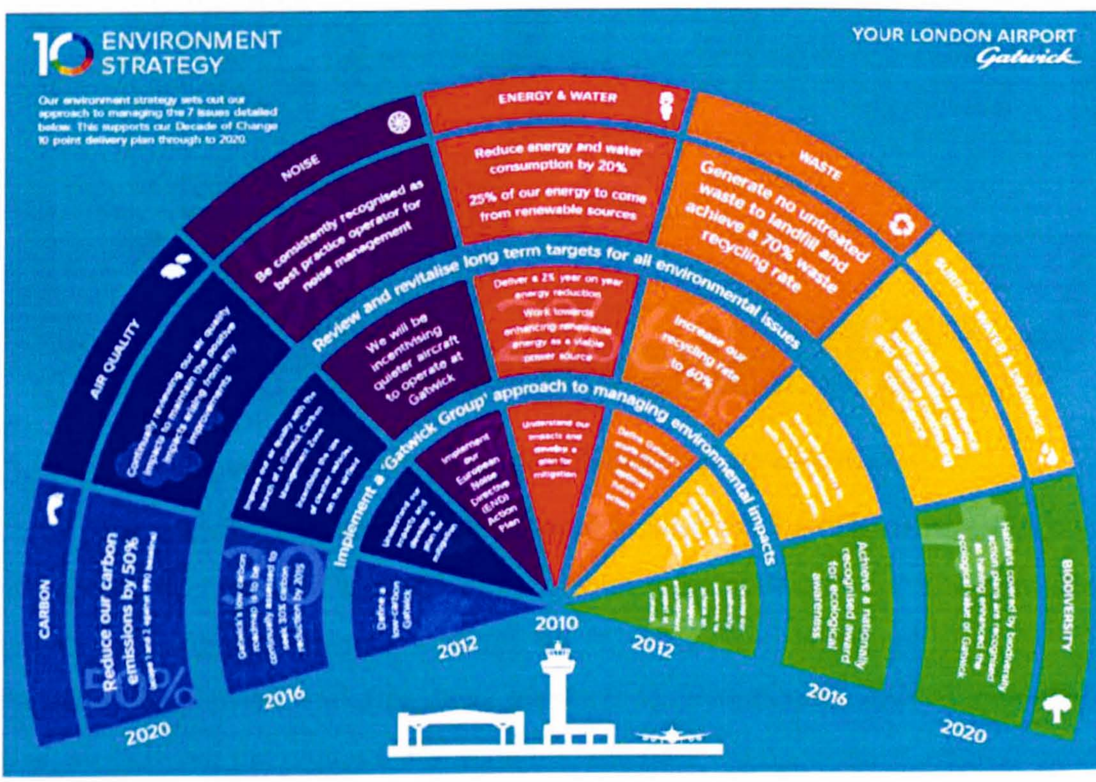

Figure 98: Airport Environment Strategy

Developing a value improvement model operationalising the environment strategy, in Figure 99 the Author shows how the strategy delivery process could be managed including the internal and external influencing factors. The repetitive process is shown as the Airport operating system transferring passengers and planes between their destinations with all of the subsequent supporting services. Providing a service to support this process (from an Airport operational perspective) the resource bundles are split between the development team influencing the future state of the Airport and the operational team influencing the current state. The customer requirements are shown as the environment strategy including the delivery of a 10 point plan by 2020.

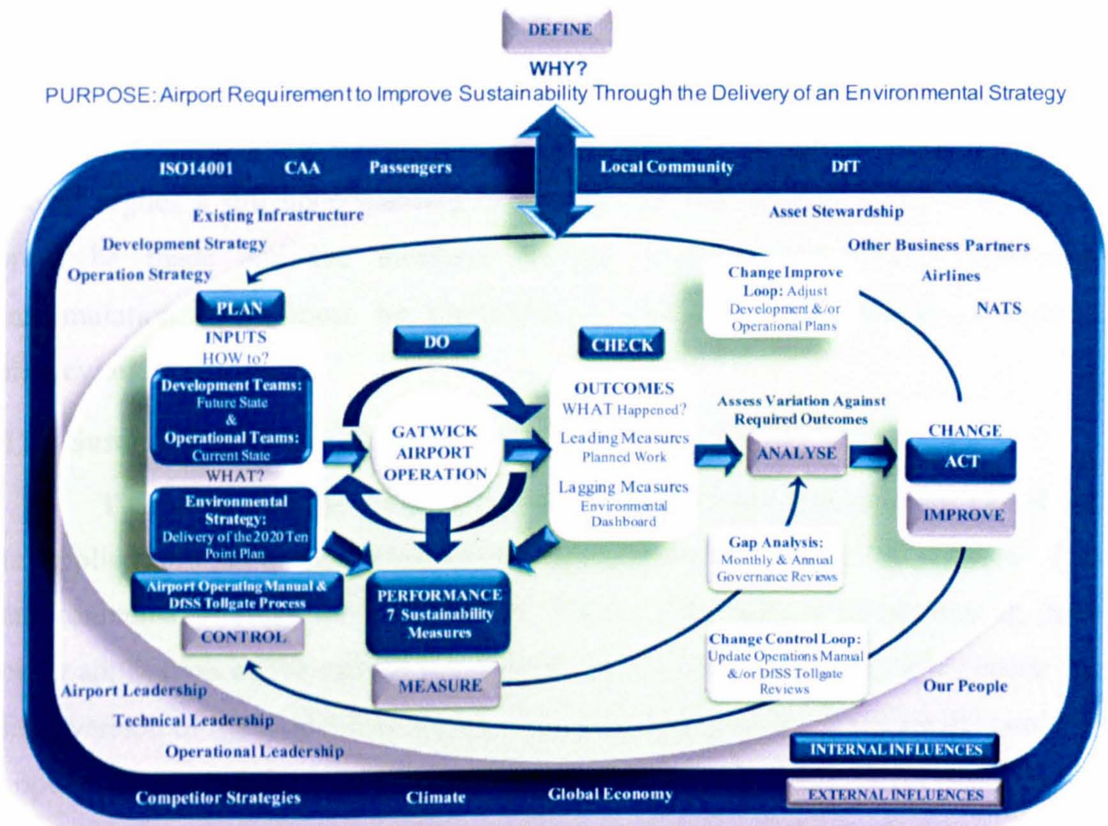

Figure 99: Sustainable Airport Value Improvement Model

The measurement framework is based around the 7 issues discussed earlier and should be structured around Leading measures of planned work to achieve the targets and Lagging measures through an environmental dashboard showing the impact of the planned work (the direct measures in relation to the 2020 targets). Gap analysis between the required and actual is managed through a governance process encompassing monthly meetings for the implementation teams and yearly meetings for the executive team.

Changes are fed back into the repetitive process inputs via the resource bundles in this case either changing the future state prediction through the development team work or through changing the work practices of the current operation. For example the shuttle system discussed earlier is an example where the shuttle currently runs 24 hours per day. The environmental impact of this could be measured and operating hours adjusted to suit passenger demand.

Internal influencing factors can be split into two main areas. The first area consists mainly of the Airport operating partners such as NATS[82], airlines, ground handling teams and retailers. The second area is made up of the Airport internal strategies. External influences are quite ranging from the CAA led CAP168 aerodrome licence to the ISO 14001 Environmental Management Standard.

In summary, to achieve the environment strategy the value improvement model argues a full understanding of the internal and external influencing factors must be made and the measure, analyse, improve and control knowledge accumulation cycle must be implemented through the suggested governance framework.

11.4 Summary & Conclusions

This section of the thesis has shown how the value improvement model can be applied to a stores and inventory management system and to the delivery of an environmental strategy for a sustainable Airport. The purpose of introducing these other application of the value improvement model was to illustrate how generic the final version of the model had become. The author now believes the model could be applied to any repetitive process within either a manufacturing or service industry environment based on the applications demonstrated in this and the preceding Chapters.

The next and final Chapter of the thesis will present the conclusions from this research investigation into the development of a value improvement model for repetitive processes.

[82] National Air Traffic Services operating under licence from the CAA.

Chapter 12: Conclusions

12.1 Introduction

This concluding Chapter will re-visit the research hypothesis and research questions and discuss the outcomes of the research investigation including any contributions to the body of knowledge:

Systems Thinking, combined with developments to both the Six-Sigma: Define→ Measure→ Analyse→ Improve→ Control (DMAIC) framework and the Lean customer focused value philosophy, can be used to develop a value improvement model for repetitive processes useful to both manufacturing and service industry applications.

Reflecting on the research investigation, the research challenges, strengths & limitations and & impact of the value improvement model will also be briefly discussed[83] Finally, based on gaps identified in both the practitioner and academic bodies of knowledge, opportunities for future research are also discussed.

12.2 The Development of a Value Improvement Model for Repetitive Processes

Developing a value improvement model basic framework, Table 20 summarises the seven 'P's proposed by the Author to provide an understanding of the different elements and their inputs to the model development.

P Value	Application on the Value Improvement Model
Purpose	Justification for the development of a value improvement model, questions the need to change.
Perspective	Shown in the external influencing band, questions if the world views of the different affectees of the repetitive process are understood.
People & Plant	Direct inputs to the repetitive process, questions how the resources are bundled together to provide a service to the repetitive process.
Product	A direct input to the repetitive process and provides the value statement. For manufacturing the product will be something hard and physical, for the service industry the product will be soft and subjective.
Process	The repetitive process itself and the supporting process information to be used by the resource bundles.
Performance	Understanding the outcome of the repetitive process in relation to efficacy, efficiency & effectiveness so that the actual can be compared against the expected.

Table 20: The 7Ps of the Proposed Value Improvement Model

[83] A full discussion covering the research reflections in made in Appendix D.

Linking to the 7Ps and also showing the overlap between the hard (physical) and soft (human) systems elements of the value improvement model and the incorporation of the individual developments to the lean and six sigma conceptual frameworks, the structure of the repetitive process value improvement cycle is defined as follows:

Step 1 **Define:** Understand what the *Purpose* of the investigation is from the Business' *Perspective*? Quantify the change required perhaps using the six-sigma project charter approach.

Step 2 **Plan**: Understand how the resource bundles of *People* and *Plant* are aligned to deliver the customer needs detailed in the *Product* description. Perhaps using the lean resource mapping framework and lean recruitment frameworks presented in Chapter 6 & Appendix A.

Step 3: **Do:** Run the repetitive *Process* to deliver the *Product*. Perhaps understanding the process using the six-sigma SIPOC process mapping tool presented in Chapter 3.

Step 4: **Check/Measure**: Understand the outcomes of the repetitive *Process* and measure *Performance*. Perhaps using the improved OEE measure for manufacturing applications as presented in Chapter 5 or the 3Es Efficacy, Efficiency & Effectiveness for service industry applications as proposed in Chapter 9.

Step 5: **Analyse:** Analyse the *Performance* comparing the actual outcomes against those specified by the *Product* quantifying examples of waste (perhaps including the 8th waste of lean, 'polarisation' as presented in Chapter 6) and process variability (six-sigma) against the customer *Perspective (Product)* and business *Perspective (Purpose)*.

Step 6: **Improve/Act:** Change the *Process* inputs based on the outcome analysis.

Step 7: **Control:** Put in place control mechanisms to ensure the *Process* changes are sustained. Perhaps using the 5S approach to sustainable business improvement presented in Chapter 4.

Step *n*: Start again revisiting the *Purpose & Perspective*.

Developing a conceptual framework to operationalise the model in a practitioner environment, Figure 83 introduced the generic value improvement model for repetitive processes. The model is introduced as an outcome of the individual elements of lean and six-sigma process improvement research presented in Chapters 3 through to 6 and the action case study interventions of value improvement implementation presented in Chapters 7 through to 11.

The hypothesis introduced at the start of this section has been validated and the value improvement model developed from a synthesis of systems thinking, six sigma and lean has shown it to be useful in both manufacturing and service industry applications. Supporting this validation, in Table 21 the Author presents a summary of the different types and applications of the value improvement models developed as part of this thesis, all of which have a specific use for delivering value improvements.

Title	Value Improvement Model Type	Application
Generic Value Improvement Model	*g*-VIM	Generic VIM used as a starting point for the development of a bespoke VIM for a specific repetitive process.
Manufacturing Value Improvement Model	*m*-VIM	Specific VIM to manufacturing based around a 'hard' product using OEE as a measure of performance.
Service Industry Value Improvement Model	*s*-VIM	Specific to service industry and based around a 'soft' product using bespoke measures of performance.
Current State Value Improvement Model	*c*-VIM	Current State VIM used to identify gaps in the value improvement cycles and areas for improvement in the repetitive process under review
Future State Value Improvement Model	*f*-VIM	Future State VIM used to show the future expectations of the repetitive process management team. Is used in conjunction with the current state VIM to identify gaps and develop specific improvement objectives to be implemented in loops.
Value Improvement Model Toolkit	*t*-VIM	Overlay of systems thinking, lean & six-sigma 'tools' onto VIM to show how the repetitive process can be understood and developed.

Table 21: Taxonomy of VIM Types & Applications

12.3 Contributions

This EngD thesis development has been a journey combining practitioner interventions to test and validate ideas with reflective learning and the understanding of links to the related theoretical bodies of knowledge. Quoting Blockley (2010) *"A systems thinker must be a philosopher by night and a man of action by day..."*. For the action case study approach adopted in this research investigation, the researcher was an asset management professional and research engineer by day and an academic by night.

#	Contribution Details	Location in Thesis
1	A model of 5S deployment for sustainable business improvement	Chapter 4
2	An approach to incorporating the lean OEE measure into the six-sigma DMAIC improvement process	Chapter 5
3	The development of OEE as an indicator of lean six-sigma capability	Chapter 5
4	A lean resource mapping framework for identifying an eighth lean waste classified as polarisation	Chapter 6
5	A value improvement model for manufacturing repetitive processes	Chapter 7
6	A value improvement model for service industry repetitive processes	Chapter 8
7	A generic value improvement model for repetitive processes	Chapter 9
8	A current state and future state value improvement model for management	Chapter 10
9	A new lean tool classified as a lean recruitment framework	Appendix A

Table 22: Summary of Contributions

Focusing on the contributions and reflecting back on the preceding eleven Chapters & their Appendices, Table 22 presents a summary of the contributions made by the Author. Elaborating on the contributions, the following section revisits the research questions as detailed in Chapter 1 and discussed in detail at the end of each relevant Chapter:

R1. Can 5S be applied as a philosophy for sustained business improvements or is it just a tool for housekeeping in factories specifically on the shop floor?

Chapter 4 presented an argument suggesting the Japanese 5S approach was more than just a system of housekeeping and could also be used as a foundation for any sustainable business improvement. A model of implementation was presented in Figure 16 (Sustainable Business Improvement Model, Page 81) arguing sustainable business improvements were dependent on 5S implementation as a prerequisite to build a steady state platform to base any changes to the process on before lean and six-sigma can be implemented. The argument is made that if 5S is not in place, then any changes made to the process could be based around invalid information possibly negatively influencing the process and subsequently business improvements are not made.

R2. Can the lean measure of overall equipment effectiveness (OEE) be used within a six-sigma DMAIC improvement process?

The first section of Chapter 5 presented a case study example of how the lean measure of overall equipment effectiveness could be incorporated into the six-sigma Define→Measure→Analyse→Improve→Control improvement process. The approach was successful and the manufacturing process OEE measure improved from 34% to 62% in the case study presented.

R3. Can the measure of OEE be expanded to incorporate asset management indicators and a level of six-sigma capability giving a holistic indicator of lean six-sigma capability?

The second part of Chapter 5 introduced another case study example of how the OEE measure could be developed to incorporate indicators of asset management efficiency and effectiveness and also provide an indication of six sigma capability. Figure 28 (OEE Value Analysis System Map, Page 111) presented a systems map of how OEE could be further developed encompassing these ideas as well as showing the relationship to the value-adding, non-value-adding and necessary non-value-adding categories of lean waste.

R4. Will a new lean tool introduced as a lean resource mapping framework complement the extant lean conceptual framework through the introduction of an 8^{th} waste classified as polarisation?

Chapter 6 introduced the lean resource conceptual framework which was operationalised through the identification of an eighth waste classified as polarisation. A conceptual model was presented in Figure 34 (Lean Resource Conceptual Framework, Page 127) and a practical framework was demonstrated through two case study applications developing a lean resource mapping matrix as presented in Figure 41 (Lean Resource Matrix Template, Page 137).

R5. Can the DMAIC, 5S, OEE, lean resource mapping framework and the lean recruitment framework tools be incorporated into the development of a single value improvement model for repetitive processes in manufacturing?

Chapter 7 presented a discussion on how the value improvement model was developed from the individual elements of lean and six sigma related research presented in Chapters 3 to 6 and a 1st draft conceptual model was presented in Figure 54 (Value Improvement Model for Repetitive Processes 1st Draft, Page 162) overlaying the 5S, OEE, lean resource mapping and lean recruitment frameworks. Operationalising and testing the usefulness of the value improvement model, a case study example was presented and a value improvement model was developed for a manufacturing extrusion repetitive process as shown in Figure 56 (Value Improvement Model for Manufacturing Process, Page 164).

R6. Can the manufacturing value improvement model be adapted for use in a service industry environment?

Chapter 8 presented a case study example discussing how the manufacturing value improvement model for repetitive processes could be developed to be applicable to a body scanner security process within a busy International Airport. Figure 64 (Value Improvement Model for a Body Scanner Process, Page 177) presented an example of a service industry value improvement model identifying the main difference with the manufacturing value improvement model to be in the understanding of process performance.

R7. Can the value improvement model be further developed to a more generic level moving away from the specific lean tools such as 5S and OEE by applying systems thinking?

Chapter 9 presented a case study example operationalising the value improvement model using systems thinking in an operational engineering application. Section 9.3 of this thesis has discussed the development of a generic value improvement model and Figure 83: Generic Value Improvement Model for Repetitive Processes, Page 214) presented the conceptual framework.

R8. Can the generic value improvement model be further developed to incorporate a current state map and future state map of the repetitive process under review?

Chapter 10 presented a case study example based around the asset management of an Airport inter-terminal Shuttle transportation system. The case study discussed the concept of a '*current state value improvement model*' (Figure 86: Current State VIM for Shuttle Asset Management, Page 219) providing both a visual and descriptive image of the extant problems with the Shuttle asset management system. Looking to overcome these problems '*a future state value improvement model*' (Figure 89: Future State VIM for Shuttle Asset Management, Page 223) was developed providing a visual and descriptive image of the future expectations of the Shuttle asset management system. Comparing the current and future state models, the gap between the required and actual was translated into the development of improvement objectives.

A new lean tool classified as a lean recruitment framework

One final contribution is presented in Appendix A which introduces a lean recruitment framework and demonstrates its effectiveness through a case study example. The model presented in Figure 103 (Controlled Divergent/Convergent Recruitment Process, Page 280) shows how the number of potential candidates is reduced using the Pugh matrix to facilitate convergent decision making in parallel to controlled divergent data collection about the individual candidate suitability to match the role criteria.

Summary of Contributions

The main contribution which can be extracted from this thesis is the development of a value improvement model for repetitive processes as presented in Figure 83 with the taxonomy of types and applications presented in Table 21. Supporting these models and their applications, the following lists the other uses for the value improvement model presented in this thesis:

- Method of Visualisation
- Method of Modelling

- Method of Feedback
- Method of Disciplined Working
- Method of Understanding
- Method of System Thinking
- Method of Systems Working
- Method of Problem Solving
- Method of Strategic Planning
- Method of Communication
- Method of Impact & Motivation
- Method of Process Improvement

12.4 Research Reflections

With the portfolio of research investigations presented in this thesis, it is useful to reflect on the development of the value improvement model understanding the challenges the researcher faced when completing the research while working for a business in a full-time role and not as a researcher based at a University. Also important is to reflect on the usefulness of the value improvement model from a practitioner perspective, understanding the strengths and limitations and also the impact and value which can be realised through the application of the model. Appendix D reviews these reflections in more detail with an overview of the main reflections presented in the following sub-sections.

12.4.1 Research Challenges

Throughout the development of the value improvement model the author always focused on achieving an output that would be useful from both a practitioner perspective and also satisfy the expectations of academia for research at a doctoral level. Of all of the challenges and issues throughout the research project, managing the expectations of both the employer (who expect a useful output/outcome with some impact to the business during and at the end of the research) and the University (who expect quality research which has gained peer recognition through publication in academic conference proceedings and journals) was the most difficult.

12.4.2 Value Improvement Model Strengths

One of the underlying strengths of the value improvement model is the focus on repetitive processes rather than one-off activities. By focusing on repetitive processes, the value improvement model can be built around an accumulated knowledge of what has actually happened allowing improvement decisions to be based on the evidence of antecedent process performance. The feedback loops of the value improvement cycle also inform future investment decisions creating a continuous value improvement action cycle based on quantifiable evidence. Therefore, as the maturity in process knowledge accumulation increases through the value improvement model implementation, so do quantifiable and justifiable opportunities for positive interventions for process improvement to be made. With a one-off process there is not necessarily the maturity and knowledge accumulation to create a value improvement cycle.

12.4.3 Value Improvement Model Limitations

Although the value improvement model has been proven to be a useful methodology for understanding and process improvement, there are some limitations which the researcher encountered during the application. Perhaps the most important limitation to understand relates to the adoption of the value improvement model. For example, the value improvement current and future state models can be used to identify gaps, but on their own, will not translate the current to the required future state. For this to happen, management intervention is required. Therefore, the success of the value improvement model application is dependent on the engagement of the 'actors' within the repetitive process perhaps through understanding the existing culture of the organisation.

12.4.4 Impact & Value

Chapter 3 introduced the concept of lean and the focus on a value-adding philosophy which was used in conjunction with the six sigma DMAIC framework to develop the value improvement model through Chapters 4 to 10. The *m*-VIM discussed in Chapter 7 used OEE as a measure of value understanding the customer requirement, the value-adding part of the process. Any deviation from the value-adding was translated to inefficiencies through the OEE measure. Linking OEE with a monetary value, the estimate for each 1% of OEE was approximately £18.5k PA with savings in material, resources and reduced costs of re-manufacturing non-conforming products. In summary, the impact and value adding contribution for the manufacturing case study presented in Chapter 7 was:

- OEE increased from 34 % to 85% giving a value improvement of £18.5k x 51% = £943k PA[84].

For the body scanner example presented in Chapter 8, the value adding contribution of the improvements cannot be calculated in the same way as when using OEE. In this example, OEE was not appropriate and therefore a measure of Mean-Time-Between-Scans (MTBS) was developed to understand the capability of the process. The impact of this is simply the requirement for less body scanners and security officer to process the same number of passengers. With an estimated 33million passengers per year, all passing through security screening and an average cost per security officer of £35k PA (minimum of two security officers per body scanner) and the cost of the body scanner equipment being £100k per unit, an estimate of potential cost saving and impact can be made. Based on this estimate, the impact and value adding contribution to the security body scanner process discussed in Chapter 8 was:

- MTBS reduced from >420 seconds to <180 seconds, a 57% reduction, giving a potential 'cost to operate reduction' of £170k x 57% = £97k in costs per body scanner deployment (£39.9k PA labour, £57.1k one-off equipment). This saving would be multiplied by the number of body scanners required to match the future DfT requirements which has not yet been specified (could potentially be ten to twenty units giving a cost to operate saving of between £970k (£400k PA labour, £570k equipment) to £1.94million (£800k PA labour, £1.14million equipment).

The value improvement model developed in Chapter 9 was used to set-up an asset management value improvement cycle using airfield engineering operations as a case study. Rather than being a process improvement initiative with immediate benefits (as was the case in the two previously discussed case studies), in this instance the value improvement model was used at a more operationally strategic level and therefore it is not possible to understand the short-term impact in monetary terms.

[84] The assumption is made that there is a linear relationship with the OEE improvement % to £, however in reality this is probably not linear but for the sake of quantifying the value impact, the Author argues this approximation is acceptable so long as the Company accountants are happy to approve the financial benefits in OEE % saving (as was the case in this example).

The Shuttle case study presented in Chapter 10 identified explicit gaps in the value improvement cycle. Understanding the impact and value adding contribution for this case study:

- Shuttle nuisance alarms[85] were reduced from >66 000 to <14 000 and using Chi-Square analysis, the value improvement process identified 10 000 of the remaining alarms were being generated during normal operations.

12.5 Future Work

Building on the previous section, throughout this research investigation the author has observed interesting situations perhaps worthy of future research. Some of these observations and discussions points have been captured in the footnotes of this thesis. This section will now re-visit some of these footnotes proposing future research opportunities for those researchers with a similar interest:

- *Footnotes 15 & 16* touched on the authors own experience of the 5S system introduced in Chapter 4 and an interpretation of soft (human) systems thinking in a particular setting. Perhaps future research could look to expand upon this softer side of 5S which the author feels is encapsulated in the 4^{th} & 5^{th} Ss, Seiketsu & Shitsuke.
- *Footnote 24* is based on the author's own experience of six-sigma projects where a common phrase used is *'we cannot boil an ocean'*, in other words, we cannot fix everything and we need to focus on the problem in front of us. The SIPOC tool is used to set the scope of the six-sigma project and anything falling outside this scope-which may have an influence, positive or negative- is not necessarily included in the investigation. Perhaps future research could look to develop the SIPOC tool in conjunction with using the soft systems CATWOE tool providing a more holistic framework for intervention. Perhaps the development of a soft systems approach to six-sigma would be a good EngD project?
- *Footnote 68* is a comment based on the author's own experience of dealing with six sigma projects and Black Belts and Master Black Belts in industry and academia. When a process is performing better than expected it will fall outside

[85] These alarms are classified as nuisance as they do not necessarily mean the system has failed but there is an unplanned event with the system which potentially could lead to a system failure. With so many alarms it is difficult to know which alarms are important and which are just 'noise' in the system.

the tolerance band just the same as it would if it was performing worse than expected. In six-sigma, the focus on looking at the numbers only and indices such as Cp & in particular Cpk perhaps can lead to a misinterpretation of data. This was evident in Figure 70: Capability Study after SOP Implementation, Page 184, where the process performance is considerably higher than expected but the mean falls outside the tolerance band resulting in a negative and low value of Cpk. Perhaps future research could investigate a softer (human) approach to interpreting hard (physical) data and maybe link to the comments above in reference to *Footnote 24.*

- *Footnote 75* is based around the author's reflective appreciation of the benefits of using the CATWOE tool in the development of Lagging measures of asset management discussed in Chapter 9. Perhaps future research could look into the use of CATWOE and develop elements such as the 'Actors' using other tools such as RACI, as discussed in Chapter 9.
- *Footnote 76* asks what could be a measure of success for action research from a practitioner perspective rather than the typically discussed academic contribution(s)? For the author's own research discussed in this thesis -and as the academic theories presented in the conceptual frameworks were operationalised in a practitioner environment- the practitioner measure of success was indicated by the level of interest shown by other practitioners wanting to use or be a part of the research intervention(s). Perhaps future research could look at the practitioner benefits and impact of action research rather than just cover the philosophical and research validity/reliability viewpoints from academic perspectives.

12.6 Summary & Conclusions

Finally, this research project has introduced the development of a value improvement model as a useful visual and systematic framework enabling managers to understand, assess and improve repetitive processes within their businesses complimenting the extant lean and six-sigma conceptual frameworks. Future research should look to further develop the value improvement model for repetitive processes, perhaps focusing on developing a self-perpetuating process improvement cycle translating the 'current state' model to the 'future state' in individual, but interconnected and economically quantifiable steps.

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Appendix A: Developing a Lean Recruitment Framework

Introduction

Supporting the lean resource mapping framework presented in Chapter 6 this section of the thesis introduces the concept of a lean recruitment framework. Introduced as a new lean tool this Appendice is based upon a peer reviewed paper (double blind review) presented at, and published in the conference proceedings for the Seventeenth International Conference on Flexible Automation and Intelligent Manufacturing held at the University of Teeside in July 2009 (Gibbons, 2009).

Background to Research

Typically, recruitment processes focus around the short listing of candidates validating suitability against the submission of a curriculum vitae or job application form before further validation against a standard company interview template through a multiple interview process. Divergent information gathered on individual candidate suitability is compiled in parallel to a convergent decision making process identifying the most suitable candidate overall. Hiring managers work closely with their human resources subject matter experts looking for the most effective method of assessing candidate suitability to perform to the job specification requirements balanced against their own constraints such as time and availability. Observed problems with this type of recruitment process can lead to the subjective assessment of a candidate's suitability to match the real requirements of the hiring manager which are only identified once the candidate has been employed.

This thesis argues a more holistic approach -taking into account the business strategy whilst encompassing a focus on the functional requirements of the role- will deliver a lean and more effective recruitment process. Testing the lean recruitment framework in parallel to the extant recruitment process, the Pugh concept matrix (Pugh, 1990; Pugh *et al.*, 1996) is introduced as a useful and transferable tool. Developed from its origins as an engineering concept design review tool, the Pugh concept matrix is further enhanced into an iterative decision making tool for identifying candidate strengths, weaknesses and similarities against a datum point of individual position profile criteria.

Outputs of the research include a proposed lean recruitment framework introducing a data based candidate selection process focusing on the value adding elements through the recruitment process.

Pugh Matrix Concept

Pugh (1990) is responsible for the seminal work introducing the concept of total design, a systematic activity focused on satisfying the needs of the customer through a design process encompassing product, process, people and organization attributes. Pugh (1990) & Pugh *et al.* (1996) developed tools focused on the product attribute development arguing this is the most important element of total design as businesses cannot exist without products. Developing the framework further, product development in the total design process is based around the needs of the customer articulated through a product design specification (PDS). The PDS is used as a datum point through the design process placing a boundary around potential design concepts matched to the customer requirements.

Critical to the successful development of a new product design is the ability to generate solutions to the design problem and then evaluate these solutions selecting the one which is best suited to the PDS. Pugh (1990) argues in practice, the wrong choice of concept can rarely be recouped by brilliant detail design. Facilitating the design decision process a comparison matrix is introduced as a useful evaluation tool for comparing different concepts against individual design criteria identified in the PDS.

			Concepts					
			1	**2**	**3**	**4**	**.....**	***n***
	1		-	S	-	S	S	S
	2	D	S	S	S	S	S	S
	3	A	S	S	S	S	S	S
Criteria	**4**	T	+	+	-	-	-	-
	5	U	+	+	+	S	-	-
	....	M	S	S	-	-	+	+
	n		+	+	+	-	S	-
Total	S		3	4	2	4	4	3
Total	+		3	3	2	0	1	1
Total	-		1	0	3	3	2	3

Figure 100: Pugh Concept Matrix (Thompson, 1999)

Figure 100 shows an example of the Pugh concept evaluation matrix model (Thompson, 1999) as introduced in the total design process (Pugh, 1990).

Operationalising the matrix, each design concept is compared to a pre-defined datum point of design criteria (as defined in the PDS). Decisions are then made by the design team as to whether the individual concept elements are the same as the datum point (indicated by an 'S'), better than the datum point (indicated by a '+'), or finally worse than the datum point (indicated by a '-'). Once the matrix has been fully populated a summary table at the bottom of the matrix shows the individual concept's ability to match the requirement as well as the strengths and weaknesses in the concept design.

Pugh (1990) suggests key outputs of the evaluation matrix include:

1. A greater insight into the requirements of the specification
2. A greater understanding of the design problems
3. A greater understanding of the potential solutions
4. A knowledge of the reasons why one concept is stronger or weaker than another.

Current State Recruitment Process

The key principle supporting the lean conceptual framework has been identified as a need to understand what is value adding from the customer's perspective (Womack and Jones, 1996a; 1996b) and any subsequent non-value adding activities are classified as waste and can be eliminated (Ohno, 1988). For the recruitment process the customer would typically be the hiring manager who will usually look for support from the human resource subject matter experts taking reference to company recruitment policies and procedures. Therefore, key to the identification of a lean recruitment process is an understanding of what is value adding in the recruitment process for the hiring manager and for the business overall.

Once the value adding element is understood -using the value stream mapping approach from the lean conceptual framework- a current state map (Jones and Womack, 2003) can be completed as a platform to build a future state map of the required process which can be achieved using staged plans known as loops (Rother and Shook, 1998). The use of staged plans is sometimes necessary as in some cases the realization of a future state map in one big leap is not always possible and therefore the ideal state map can be used as an end goal pseudo objective utilizing future state maps as incremental leaps (Jones and Womack, 2003).

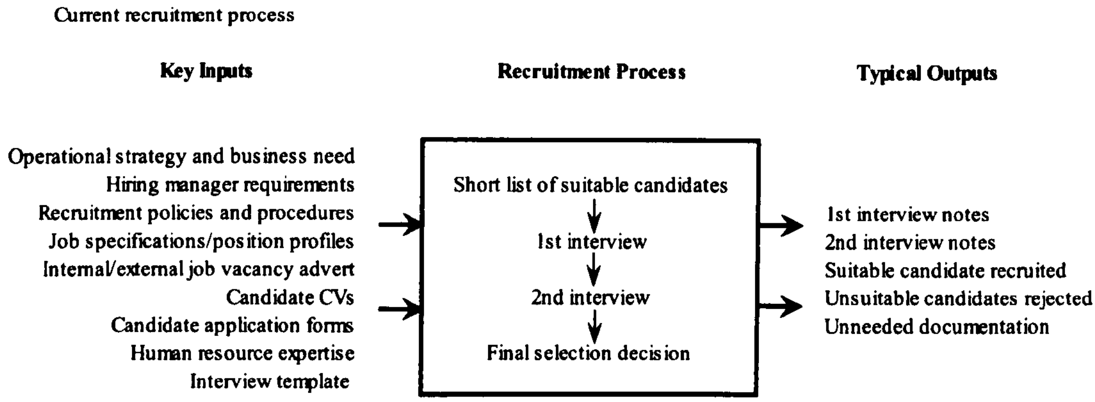

Figure 101: Recruitment Current State Map

In Figure 101 the Author presents an input-process-output model of a typical recruitment process in this case identifying the current state of the hiring manager's value stream. Key inputs focus on the business strategy and needs giving a requirement to source a suitable candidate through the recruitment process culminating in the final selection and subsequent hiring. The value adding elements of the identified recruitment inputs-process-outputs would focus on the key outputs including the selection of a suitable candidate to match the requirements of the hiring manager and the supporting documentation compiled during the recruitment process which could be used by the hiring manager to plan any personal development required for the recruited candidate.

Reviewing the key inputs to the identified process there is an overlap of information relating to the documentation prepared by the hiring manager including job description/position profile, internal/external job advert and interview template. Matched to this is the submission by potential candidates of completed job application forms, CVs or both. Through the recruitment process, reference is made to the candidate's job application form and/or CV and further data is collected during the interview phase as to the candidates' suitability to match the requirements of the hiring manager using the standard company interview template.

Future State Map & the Lean Recruitment Process

In the eyes of the customer -in this case the hiring manager- the value adding element of the recruitment process has been defined as the final selection of a suitable candidate matched to the real requirements of the business realized through the deployed manufacturing strategy. The current state map of the recruitment process has identified process waste (Ohno, 1988) extant in the form of a duplication of customer owned reference documentation, multiple comparison documentation submitted by the potential candidate and added to through the short listing and interview phases by the customer and finally a lack of focus through the selection process on the real requirements of the hiring manager resulting in a subjective decision making process based on divergent and disparate data.

The future state map should therefore look to focus on the requirements of the hiring manager using these requirements as a central datum point during the recruitment process. Subsequently, any reference material and investigative techniques should focus on the comparison of the candidates suitability matched to the requirements of the hiring manager as defined in the position profile/job description owned by the hiring manager. Reference to this documentation through the recruitment process will ensure the final selection is based on the specific requirements of the hiring manager ensuring the selected candidate will fulfil their own as well as the business expectations.

Operationalising the future state map, key inputs to the recruitment process should focus on the preparation of a position profile by the hiring manager matched to their manufacturing strategy. This document can then be used to create an internal/external vacancy advert before being used throughout the recruitment process as a central datum point to compare candidate suitability. Also important is to ensure candidate applications are made using a standard application form therefore collecting data which is easily transferable in comparison to the position profile. This would be especially useful at the short listing element of the recruitment process where the hiring manager will have many applicants to consider matched to their own time constraints.

Revisiting the total design conceptual framework focusing on the product design specification (PDS) (Pugh, 1990; Pugh *et al.*, 1996) and the Pugh concept comparison matrix (Thompson, 1999), there is opportunity to adapt and transfer this approach to the recruitment process forming a foundation for the creation of a lean recruitment conceptual framework and more importantly a method of realizing the future state map requirements. Developing the lean recruitment conceptual framework, the PDS in the design phase can be used to create a datum point of key criteria to the overall requirements of the designer.

Similarly, the position profile suggested in the future state map can be populated with key criteria to the overall requirements of the hiring manager. Critical to the lean recruitment process at this stage is the capture of realistic requirements of the hiring manager as specific criteria in the position profile, as this will be the datum point for candidate comparison through the recruitment process. Also important is the matching of the position profile criteria to the manufacturing strategy ensuring alignment to both business and departmental objectives. During the candidate selection phase the hiring manager can compare individual candidates (the concept designs) to the requirements detailed in the position profile (the PDS).

		Short listing					1st Interview				2nd Interview		
DECISION CRITERIA	DATUM	Candidate A	Candidate B	Candidate C	Candidate D	Candidate...	Candidate A	Candidate B	Candidate C	Candidate...	Candidate A	Candidate B	Candidate...
Role purpose	Specific example	+	+	+	S	+	+	+	+	S	+	+	+
Skills required	Specific example	S	S	S	S	S	S	S	S	S	S	S	S
Experience required	Specific example	-	S	-	-	-	-	S	-	-	-	S	-
Knowledge required	Specific example										s	+	-
Qualifications required	Specific example	-	S	S	-	-	-	S	S	-	-	S	S
Personal skills	Specific example						-	+	-	+	-	+	-
Availability to start	Specific example	+	+	+	S	S	+	+	+	S	+	+	+
References from previous employer	Specific example										+	-	S
Skills test	Specific example										S	S	+
Leadership experience	Specific example						-	-	-	+	-	-	-

SUMMARY ANALYSIS												
S	1	3	2	3	2	1	3	2	3	3	4	3
+	2	2	2	0	1	2	3	2	2	3	4	3
-	2	0	1	2	2	4	1	3	2	4	2	4
Overall Rating	0	2	1	-2	-1	-2	2	-1	0	-1	2	-1
	Short listing					1st Interview				2nd Interview		

Figure 102: Lean Recruitment Matrix

The second element of the lean recruitment conceptual framework is the introduction of an objective decision making process when comparing candidate suitability. The framework argues the use of the Pugh matrix tool allows for the comparison of individual candidates matched to a datum point of key criteria illustrated within the position profile. In Figure 102 the Author presents a conceptual template of the lean recruitment Pugh matrix using possible criteria examples typically found in position profiles which can be added to as defined in the actual position profile. The matrix is populated by comparing potential candidates to an antecedent set of functionally required datum points. Each candidate is compared against the individual position profile criteria datum point to see if they are better than the requirement (marked as a plus sign '+' and seen as a potential strength), or the same as the requirement (marked as an 'S' and seen as matching the requirement exactly) or finally, whether they are worse than the requirement (marked as a minus sign '-' and seen as a potential weakness).

At the short listing stage, rather than complete the whole matrix for each potential candidate, the hiring manager can focus on comparing candidate suitability against a sample of key criteria. As the number of potential candidates is reduced through the recruitment process, more of the position profile criteria can be incorporated into the Pugh matrix facilitating convergent decision making through controlled divergent data collection.

Once the matrix is fully populated the summary of strengths, weaknesses and similarities is tabulated to show the potential candidates' identified strengths, weaknesses and similarities to the overall requirement. The matrix can also be developed further by weighting significant criteria as well as adding other important selection criteria not detailed in the position profile such as candidate availability if the requirement is urgent. Once the matrix is fully populated the final stage of the comparison process is to rank the potential candidates in order of suitability. At this point potential candidate weaknesses can be noted for further investigation at the next stage of the recruitment process or, if the candidate is selected for the role, the weaknesses can be carried over to their personal development plan as training requirements.

Also at this point, the potential candidate strengths can be noted for further investigation at the next stage of the recruitment process. If the potential candidate has scored very highly this may indicate they are over qualified/experienced for the role and therefore may not be suitable. However, the potential strengths identified may be useful for developing other employees and therefore the hiring manager should incorporate this into the decision making process.

As part of the recruitment process the Pugh recruitment matrix decision criteria is populated at the time of the hiring manager developing a position profile and is then updated throughout the recruitment process from short listing through to 1st interview, 2nd interview and hiring. During the recruitment process the hiring manager accumulates a portfolio of candidate suitability summarized in the lean recruitment Pugh matrix. For the candidates not selected their portfolio can be archived for future reference if required and the selected candidate's portfolio can be carried over to their personnel file and to the hiring manager's departmental skills matrix.

In summary, the future state map and lean recruitment framework eliminate the extant duplication of documentation by using the position profile (PDS) as a standard document through the initiation, advertising, selection and post hiring phases of the recruitment process in parallel to using a Pugh recruitment matrix to control the convergent candidate selection in a balanced divergent candidate data collection process.

Discussion

The lean recruitment conceptual framework was developed and tested using an action research approach using multiple case studies including pilot studies and semi-structured interviews to feedback the user comments to refine the tool. Reflecting on the usefulness of the lean recruitment framework the benefits are very similar to those identified within the total design approach to product development (Pugh, 1990; Pugh *et al.*, 1996): -

A greater insight into the requirements of the specification (in this case the position profile): Through the recruitment process the hiring manager gets the opportunity to question why the requirement is important to the position profile and overall manufacturing strategy. Taking an iterative approach, the requirement criteria can be changed to ensure alignment with departmental objectives through the convergent and controlled divergent lean recruitment process.

A greater understanding of the design problems: Through the selection process the hiring manager gains an understanding of how realistic the requirement is in comparison to candidate availability. This could mean there is a skills shortage in that particular field of expertise or that the hiring manager has set an unachievable requirement. In summary, the hiring manager will gain an understanding of candidate availability to best match the requirement.

A greater understanding of the potential solutions: Linking to the understanding of design problems the hiring manager -through the Pugh lean recruitment matrix summary- gets an understanding of the possible candidates who could fulfil the roll most adequately. In particular reviewing any potential weaknesses that would require further development or any candidate strengths that could be used in the development of other personnel.

A knowledge of the reasons why one concept is stronger or weaker than another: Potential candidate suitability, strengths and weaknesses are investigated through a controlled divergent process in parallel to validation through the interview phase converging at the final selection decision stage. Through the lean recruitment process, each candidate is compared against the individual position profile criteria datum point to see if they are better than the requirement (marked as a plus sign '+' and seen as a potential strength), or the same as the requirement (marked as an 'S' and seen as matching the requirement exactly) or finally, whether they are worse than the requirement (marked as a minus sign '-'and seen as a potential weakness).

Once the final lean recruitment matrix is fully populated the summary of strengths, weaknesses and similarities is tabulated to show the overall candidates' potential to meet the requirement. The summary table can also be ranked to show order of candidate suitability and key criteria can be weighted to ensure the candidate assessment is correctly balanced to the requirements.

In summary, the main benefit of the lean recruitment process is the shift in emphasis to focus on the value adding elements of the recruitment process in parallel to placing more ownership with the hiring manager. The Author argues that through the recruitment process, the framework provides a useful and correctly balanced convergent/divergent (*cf.* Figure 103) decision making approach for non-HR specialists to use, giving ownership of the selection process through comparison of their realistic requirements as defined in the position profile and analysed in a lean recruitment Pugh matrix. However, as with the total design framework, where the wrong choice of concept can rarely be recouped by brilliant detailed design work, the wrong choice of candidate at the recruitment stage cannot necessarily be recouped by brilliant personnel management skills when the selected candidate is employed.

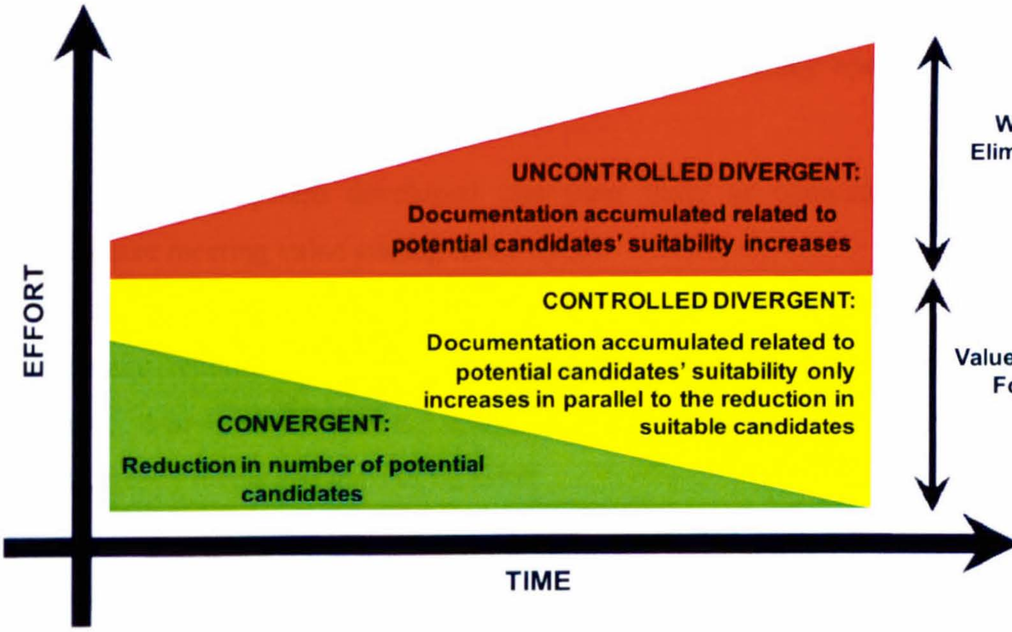

Figure 103: Controlled Divergent/Convergent Recruitment Process

Conclusion

The lean recruitment framework has been introduced as an objective recruitment framework focusing on the value adding steps to ensuring the right candidate is employed matched to the realistic requirements of the hiring manager.

Appendix B: Other Achievements & Activities

Other tools and activities completed during the EngD journey which are of interest include:

- Lean meeting system developed and used daily at Gatwick and Cummins. Maximise meeting value adding time.
- A4 for project management tool based around 4Ps: People, Product, Plant, Process summary (real time communication tool for project managers and their teams)
- 1-in-4, 4-in-1 skills matrix linked to lean recruitment framework. Shows competency levels and gaps to be filled.
- Developed a lean thinking training exercise using a chair assembly challenge. Also is a team building exercise.
- Lectures on lean and six sigma at Bristol University (Introduction to Systems Module, Dr. Theo Tryfonas and Advanced Systems Module, Professor John Davies then Dr. Mike Yearworth).
- Training material developed for asset stewardship process at Gatwick and training delivered to over 200 personnel at the Airport.
- Lecture on asset management at Bristol University (Introduction to Systems Module, Dr. Theo Tryfonas).
- Lecture on research methods at Bristol University (Project Management & Research Methods Dr. Gordon Edwards).
- Won the Cummins Chairman's award for six-sigma working in a project team developing a new process for outsourcing testing of prototype generators.
- Paper reviewer (blind) for the International Journal of Lean Six Sigma. Papers reviewed entitled:-
    1. Designing an Integrative Model of Leagile Production and its Influence on the Quality of Auto Parts Based on Six Sigma Approach with a Case Study in Ghods Manufacturing Group.
    2. Integrating Lean Thinking into ISO 9001: A First Guideline
    3. An Investigation of the Assistant Manager Role in Toyota.
- Paper reviewer (blind) for the International Journal of Quality & Reliability Management. Paper reviewed entitled: -
    1. Review and evaluation criteria for software tools supporting the implementation of the RCM methodology.

- Development of the Pugh Matrix into a useful decision making tool for managers (as used in the lean recruitment process for example). Examples include selection of contractors and selection of manufacturing strategies.
- Invited to present the Value Improvement Model at Cambridge University Institute for Manufacturing (DIAL Research Group).
- Invited to present the Value Improvement Model at Cranfield University, Department for Manufacturing (EPSRC Centre for Through-Life Engineering Services).
- Invited to present the Value Improvement Model at the Department for Transport in London (Rail Interest Group).
- Invited to run a tutorial on Lean and Six Sigma at the INCOSE annual conference in 2011.
- Organised the 1st Whole Life Asset Management Best Practice Seminar which took place at Bristol University in June 2011 with key note speakers including David McKeown, Chief Executive Officer of the Institute of Asset Management and Professor Andrew Starr, Head of the Maintenance Systems Centre at Cranfield University.

Appendix C: Shuttle Individual Car Pareto Analysis

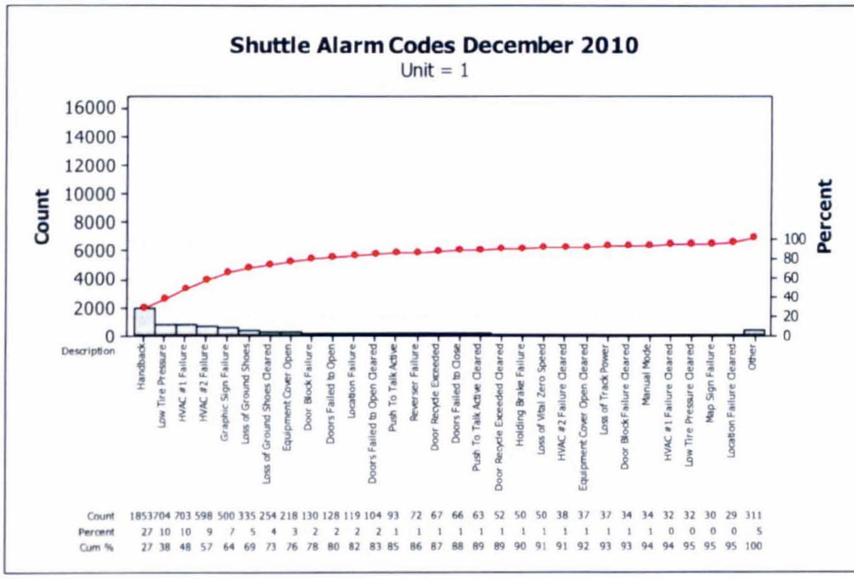

Figure 104: Shuttle Pareto Analysis Car 1

To gain a more detailed understanding of the alarm faults further analysis can be made by individual car[86]. Figure 104 shows the Pareto analysis of Car 1 showing a total of 7000 alarms for the period with failure modes 'Handback', 'Low Tyre Pressure', 'HVAC #1 failure' and 'HVAC #2' failure accounting for 57% of the alarms. Interestingly, the 'Low Tyre Pressure' alarm feature had not been installed on the shuttle system and therefore should not have been signalling an alarm.

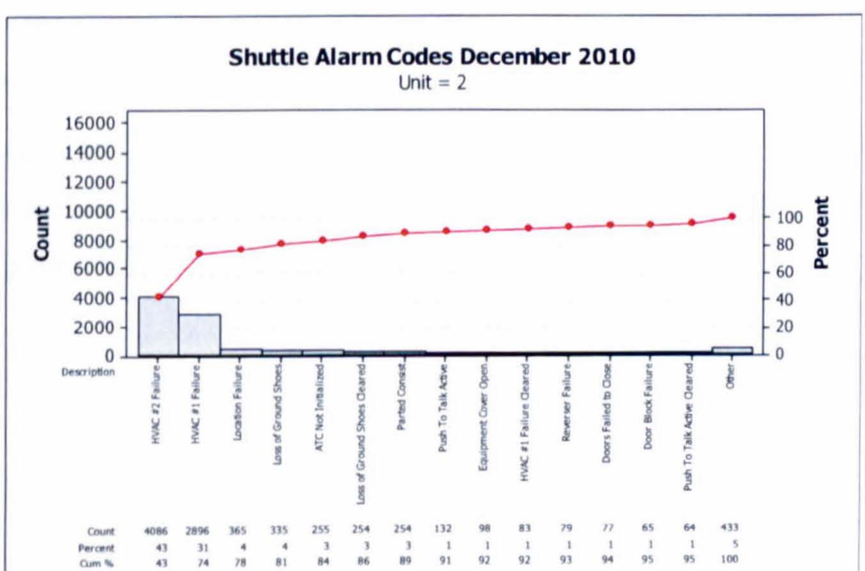

Figure 105: Shuttle Pareto Analysis Car 2

[86] As previously stated, the shuttle system is made up of two trains, each with 3 cars.

Figure 105 shows the Pareto analysis of Car 2 showing a total of <14000 alarms for the period with failure modes 'HVAC #1 failure' and 'HVAC #2' failure accounting for 74% of the alarms. An interesting comparison worth further investigation is the number of failure modes for Car 2 in comparison to Car 1 and the shuttle system overall. The system overall showed 37 failure modes, Car 1 showed 28 failure modes and Car 2 only 14.

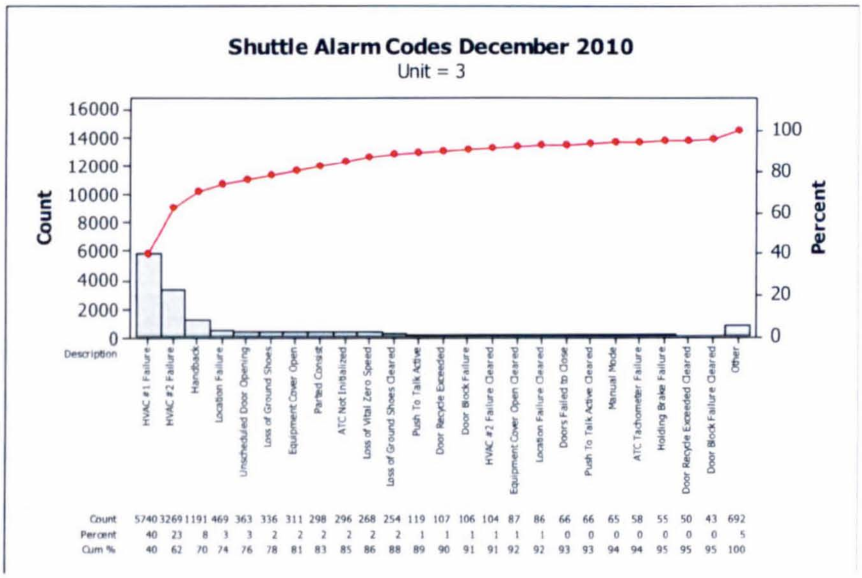

Figure 106: Shuttle Pareto Analysis Car 3

Figure 106 shows the Pareto analysis of Car 3 showing a total of <10000 alarms for the period with failure modes 'HVAC #1 failure' and 'HVAC #2' failure accounting for >64% of the alarms.

Figure 107 shows the Pareto analysis of Car 4 showing a total of <13000 alarms for the period with failure modes 'HVAC #1 failure' and 'HVAC #2' failure accounting for >52% of the alarms.

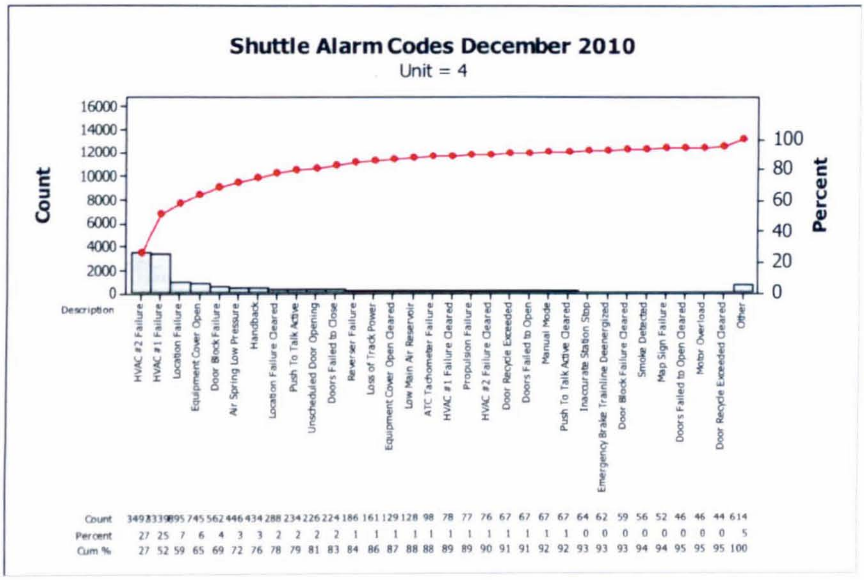

Figure 107: Shuttle Pareto Analysis Car 4

Figure 108 shows the Pareto analysis of Car 5 showing a total of <6000 alarms spread more evenly over 23 failure modes. This is distinctly different to the Pareto spreads of alarms for the other Cars and the differentiation should be investigated further.

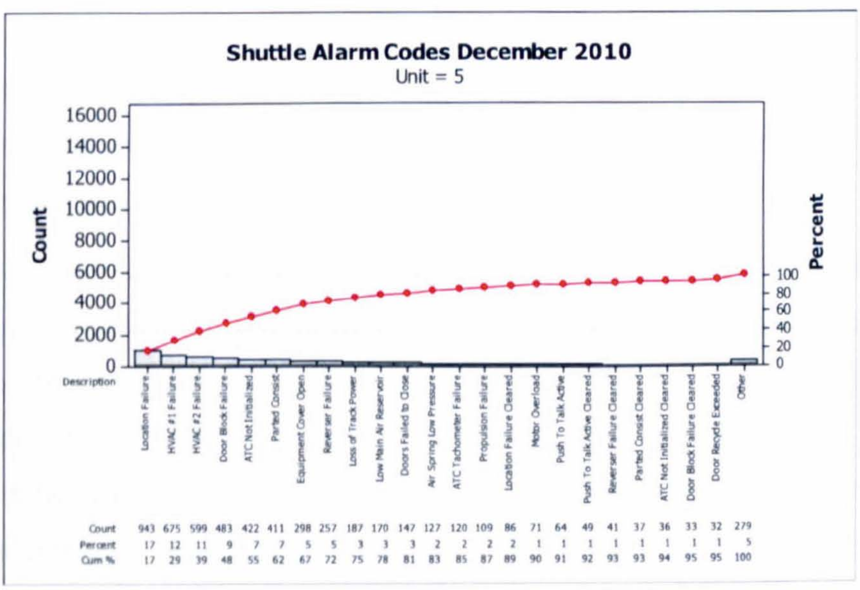

Figure 108: Shuttle Pareto Analysis Car 5

Figure 109 shows the Pareto analysis of Car 6 showing a total of <16000 alarms for the period with the failure mode 'Handback' accounting for over 4000 alarms (29%). Interestingly the 'HVAC #1 failure' and 'HVAC #2' alarms are much lower down the Pareto analysis, accounting for only 2% of the failures.

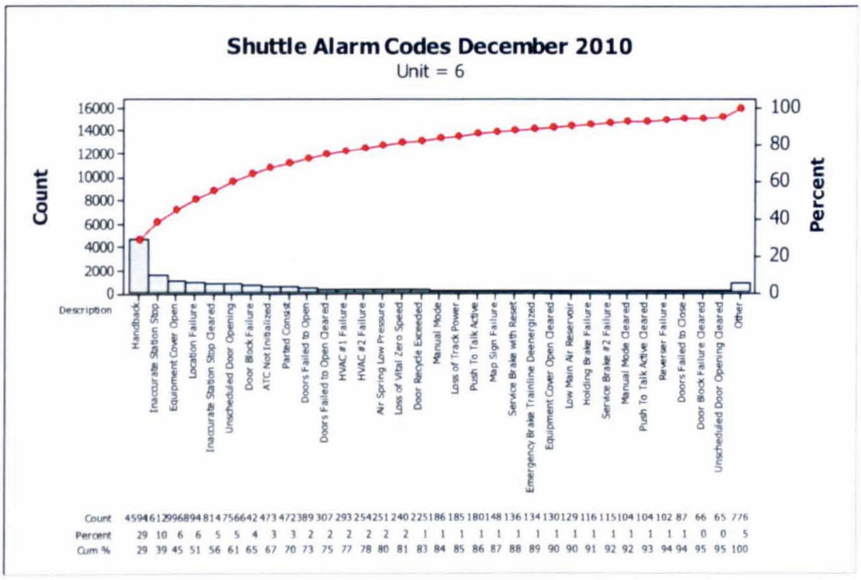

Figure 109: Shuttle Pareto Analysis Car 6

Summarising the analysis of the Shuttle Pareto alarm analysis the following questions should be answered:-

1. Why is the 'HVAC[87] failure' not evenly spread across all cars? For example: -
   - Car 6 <600 faults
   - Car 3 >8000 faults
2. Why does car 6 have >4000 'Hand back' faults?
3. Why does car 2 have considerably less alarm types than the other cars and why are 80% of the alarms on this car for HVAC?

These questions were investigated by the Shuttle engineering team and initial findings show the HVAC fault is linked to a faulty contactor and replacement parts have been ordered from the supplier. The 'Handback' fault was also investigated and the findings showed this was linked to another fault in the Pareto Analysis, 'Inaccurate Station Stop'. A solution has been identified and tested but requires a permanent change to the operating software to implement fully. The software change would need to be completed by the original equipment supplier.

[87] HVAC is a commonly used abbreviation for Heating, Ventilation & Air Conditioning.

Appendix D: Research Reflections

With the portfolio of research investigations presented in this thesis, it is useful to reflect on the development of the value improvement model understanding the challenges the researcher faced when completing the research while working for a business in a full-time role and not as a researcher based at a University. Also important is to reflect on the usefulness of the value improvement model from a practitioner perspective, understanding the strengths and limitations and also the impact and value which can be realised through the application of the model.

Research Challenges

Throughout the development of the value improvement model the author always focused on achieving an output that would be useful from both a practitioner perspective and also satisfy the expectations of academia for research at a doctoral level. Of all of the challenges and issues throughout the research project, managing the expectations of both the employer (who expect a useful output/outcome with some impact to the business during and at the end of the research) and the University (who expect quality research which has gained peer recognition through publication in academic conference proceedings and journals) was the most difficult.

A further complication to this 'balancing' challenge is the way the researcher is employed. There are typically two options: 1) are they on a Research Council/Company sponsored 'stipend'?, or 2) are they a salaried employee? For this research project the researcher was always a salaried employee completing other activities outside of the scope of the research project. However, over time, the researcher was able to develop useful models and use their impact to make the model development a part of the day job. This is evident in the Shuttle case study example model development which led to opportunities to develop the Stores & Inventory Management and Environmental value improvement models presented in Chapter 11. Finding a link between the theoretical and practical combined with an opportunity to test and develop new theories in a practical environment was a critical element in the development of this thesis.

Perhaps, the combination of balancing practitioner and academic expectations can be managed by knowing the audience you are engaging with. For example, the shuttle current state and future state models presented by the Author in Figure 86 & Figure 89 are very useful for explaining the model to practitioners and they are also well received by academics who are interested in understanding the model implications in a real-world environment. However & in contrast, the generic value improvement model (on its own) presented in Figure 83 would be deemed as too academic for practitioners (the author has experienced this first-hand) perhaps de-valuing the model in the eyes of the practitioners but the same model would be acceptable to academics, in this case for understanding the link between soft (human) and hard (physical) system thinking.

Value Improvement Model Strengths

One of the underlying strengths of the value improvement model is the focus on repetitive processes rather than one-off activities. By focusing on repetitive processes, the value improvement model can be built around an accumulated knowledge of what has actually happened allowing improvement decisions to be based on the evidence of antecedent process performance. The feedback loops of the value improvement cycle also inform future investment decisions creating a continuous value improvement action cycle based on quantifiable evidence. Therefore, as the maturity in process knowledge accumulation increases through the value improvement model implementation, so do quantifiable and justifiable opportunities for positive interventions for process improvement to be made. With a one-off process there is not necessarily the maturity and knowledge accumulation to create a value improvement cycle.

Perhaps the main strength of the value improvement model is the similarities of fundamental requirements for very different repetitive processes. This counterintuitive -generic but bespoke- approach makes the model easy to use and understand for practitioners and academics with experience of systems thinking. For example, all of the repetitive processes discussed in the case studies have resources providing a service, there is always a requirement to match a level of expectation and there is always an approach to meeting the expectations whether explicit or implicit. For the repetitive process there will also always be an output and/or outcome which will always be influenced by direct and/or indirect inputs to the repetitive process.

The value improvement model builds on this understanding to show how these fundamentals can be developed and better understood. This understanding of the interconnectivity between influencing factors of the repetitive process is what makes the value improvement model a useful development to the lean and six sigma conceptual frameworks, perhaps overcoming some of the criticisms presented in Chapter 3 and distinguishing the model from the extant lean & six sigma paradigms of operationalisation.

Through the reflective learning action research approach adopted in this research project, the *g*-VIM has been developed from an initial model which was very mechanistic, hard (physical) systems focused, and specific to product manufacturing, to being a generic model applicable to a diverse range of applications. Perhaps this proven adaptability of the *g*-VIM to be tailored for use in a diverse range of repetitive processes including product manufacturing, service delivery, asset management and general operations management applications, also in widely different industries including heavy engineering and airport operations, shows the real strength and usefulness of the model from a practitioner perspective.

However, to be successful, the adaptability of the *g*-VIM to a specific repetitive process requires system thinking learning and leadership skills. This is an important observation and potentially a limitation of the *g*-VIM to non-system thinkers. From the researchers own experience of applying the *g*-VIM, systems thinkers really appreciated the model and can understand the potential impact from adopting it, whereas non-system thinkers required much more convincing as to its usefulness.

Building on the *g*-VIM and developing bespoke value improvement models, another strength of the model -especially from a practitioner perspective- is the ability to visualise a specific process, understanding how the many individual elements are linked (or should be linked in the Shuttle current state model example) to create the repetitive cycle for value improvement. This visualisation of extant best practice and potential gaps was also found to be a useful motivator for managers of the repetitive process under review. The model explicitly shows where there are tangible (internal elements) and perhaps intangible (influencing factors) opportunities to improve giving the manager of the repetitive process a clear understanding of their process improvement opportunities.

The bespoke value improvement models were also found to be useful for communicating at multiple levels within the organisation. For example, the Shuttle value improvement models were used at the Technician level focusing on the internal and hard system elements and the need to have up-to-date information in the computerised maintenance management system to understand asset performance. At the Senior Management level the model was used to demonstrate the impact of the leadership onto the repetitive process. For example, the Shuttle value improvement model identified a potential weakness with the leadership of the repetitive process and an intervention was made based on this understanding (as discussed in Chapter 10).

Value Improvement Model Limitations

Although the value improvement model has been proven to be a useful methodology for understanding and process improvement, there are some limitations which the researcher encountered during the application. Perhaps the most important limitation to understand relates to the adoption of the value improvement model. For example, the value improvement current and future state models can be used to identify gaps, but on their own, will not translate the current to the required future state. For this to happen, management intervention is required. Therefore, the success of the value improvement model application is dependent on the engagement of the 'actors' within the repetitive process perhaps through understanding the existing culture of the organisation. For example, the leader of the repetitive process must positively promote the value improvement activity, proactively engaging with the other actors and demonstrating leadership through adoption of the Plan→Do→Check→Act approach. Sponsorship of the value improvement initiative must also be at the Owner level. Equally important is the buy-in from the 'actors' providing a direct service to the repetitive process. *Footnote 79* was made to emphasise how important the engagement of the 'actors' to a change management program was. Outside the scope of this investigation, perhaps future research could look at the cultural aspects of the value improvement model and their influence on the success or failure of the repetitive process as either a positive or negative internal influence.

Another example of a particular limitation can be demonstrated by expanding the stores and inventory management value improvement model (SIM VIM) case study presented in Chapter 11. The SIM VIM 'current state' model presented in Figure 95 identified major gaps in the value improvement cycle and through the development of a 'future state' SIM VIM (as presented in Figure 96) opportunities to improve were identified and the implementation commenced as facilitated by the researcher working closely with the SIM team. However, a senior management intervention at the 'owner'[88] level triggered by the implementation of a new material resource planning system (MRP) led to the need for a more strategic level review of the SIM systems. This activity included an intensive review of the SIM systems focusing on the location, movement, value and criticality of the inventory held. To facilitate the review an external consultant was hired, and a project team was subsequently established. The SIM VIM in this case was useful for understanding the current state of the inventory management system however, the gaps identified in the process knowledge accumulation meant the information required to complete the strategic level review was not readily available. The consequence of this was an intensive review of the raw data provided through the computerised maintenance management system, combined with an audit of slow moving and potentially obsolete inventory items.

This potential limitation of the value improvement model perhaps underlies the requirement for understanding the maturity of a repetitive process through established measures of performance. Therefore the value improvement model on its own cannot be used to make a step change to a repetitive process at a strategic level in a short space of time. The value improvement model can perhaps be used for understanding the influencing factors and even modelling different options in support of a step change initiative, but, overall the strategic level reviews are based on a one-off, in-depth data analysis informing the future state model decisions. In contrast, the value improvement model approach looks to understand the influencing factors and improve the repetitive process over time, applying the Plan➔Do➔Check➔Act approach, not the Check➔Act approach adopted in strategic level improvement initiatives where the objective is to implement a step-change improvement to the business with short-term financially justifiable returns.

Impact & Value

Throughout the thesis the model has been introduced as a value improvement model but what exactly is value, and how can it be measured? Also important and linked to understanding value, what was the impact of implementing the value

[88] This is linked to the generic value improvement model presented in Figure 83 and the 'Owner' element of the generic repetitive process (CATWOE). In this example, the 'Owner' of the SIM VIM is sitting in the internal influencing band –and not directly in the 'hard' element of the repetitive process-making a strategic business decision to change the repetitive process.

improvement models and how was value added in the case study examples presented?

Chapter 3 introduced the concept of lean and the focus on a value-adding philosophy which was used in conjunction with the six sigma DMAIC framework to develop the value improvement model through Chapters 4 to 10. The *m*-VIM discussed in Chapter 7 used OEE as a measure of value understanding the customer requirement, the value-adding part of the process. Any deviation from the value-adding was translated to inefficiencies through the OEE measure. In this example the process was improved initially from an OEE of 34 % to 62% and then with the implementation of the lean resource mapping from 62% to 85%. Linking OEE with a monetary value, the estimate for each 1% of OEE was approximately £18.5k PA with savings in material, resources and reduced costs of re-manufacturing non-conforming products. In summary, the impact and value adding contribution for the manufacturing case study presented in Chapter 7 was:

- OEE increased from 34 % to 85% giving a value improvement of £18.5k x 51% = £943k PA[89].

For the body scanner example presented in Chapter 8, the value adding contribution of the improvements cannot be calculated in the same way as when using OEE. In this example, OEE was not appropriate and therefore a measure of Mean-Time-Between-Scans (MTBS) was developed to understand the capability of the process. Translating this measure into a monetary value is more difficult as the investigation purpose was to understand the capability of the body scanner to influence the number of systems required to match the potential security requirements specified by the Department for Transport (DfT).

Developing an estimate of impact and monetary value improvement, the approach reduced the MTBS from >420seconds to <180 seconds also stabilising the process making it more predictable. The impact of this is simply the requirement for less body scanners and security officer to process the same number of passengers. With an estimated 33million passengers per year, all passing through security

[89] The assumption is made that there is a linear relationship with the OEE improvement % to £, however in reality this is probably not linear but for the sake of quantifying the value impact, the Author argues this approximation is acceptable so long as the Company accountants are happy to approve the financial benefits in OEE % saving (as was the case in this example).

screening and an average cost per security officer of £35k PA (minimum of two security officers per body scanner) and the cost of the body scanner equipment being £100k per unit, an estimate of potential cost saving and impact can be made. Based on this estimate, the impact and value adding contribution to the security body scanner process discussed in Chapter 8 was:

- MTBS reduced from >420 seconds to <180 seconds, a 57% reduction, giving a potential 'cost to operate reduction' of £170k x 57% = £97k in costs per body scanner deployment (£39.9k PA labour, £57.1k one-off equipment). This saving would be multiplied by the number of body scanners required to match the future DfT requirements which has not yet been specified (could potentially be ten to twenty units giving a cost to operate saving of between £970k (£400k PA labour, £570k equipment) to £1.94million (£800k PA labour, £1.14million equipment).
- A major impact from the body scanner value improvement model was the dissemination of a one page standard operating procedure (Figure 69: Body Scanner SOP) for use in other security processes, helping to reduce variation and increase throughput. The financial impact of this was not measured but if the impact was similar to the body scanner, then the results would be significant (57% reduction in costs to operate).

The value improvement model developed in Chapter 9 was used to set-up an asset management value improvement cycle using airfield engineering operations as a case study. Rather than being a process improvement initiative with immediate benefits (as was the case in the two previously discussed case studies), in this instance the value improvement model was used at a more operationally strategic level and therefore it is not possible to understand the short-term impact in monetary terms. Perhaps this is another limitation with the value improvement model, especially in an environment where short-term results are required to justify any longer-term changes. In this case study the value improvement model has been used at a more operationally strategic level and reflecting on the case study presented, perhaps the more strategic the value improvement model is, the longer it takes to realise the impact and financial benefit of the model.

This is a real challenge to the application of the value improvement model and perhaps future research can be used to inform an approach that combines strategic value improvements with short-term quantifiable returns helping to justify the model adoption and gaining buy-in from the repetitive process owners. Some kind of 'lacing up' process improvement perhaps, where the individual elements are linked to the overall process improvement with each step-change being used to justify the next step-change creating a self-perpetuating upward spiral towards achieving the end goal, namely the purpose statement.

In some ways, the matching of strategic level value improvements with short-term quantifiable improvements was achieved in the Shuttle case study presented in Chapter 10 through the development of current and future state value improvement models. On reflection though, this was achieved in a rather ad hoc approach with the researcher taking opportunities to make improvements as they arose. In this case-study example the current state model identified explicit gaps in the value improvement cycle and perhaps a value improvement plan could have been used to realise the future state value improvement model in a more structured way. However, the researcher was developing the current state model in this action case study example, trying to balance the practitioner impact with the testing of an academic theory. Understanding the impact and value adding contribution for this case study:

- Shuttle nuisance alarms were reduced from >66 000 to <14 000 and using Chi-Square analysis, the value improvement process identified 10 000 of the remaining alarms were being generated during normal operations. Due to the large number of alarms, at this stage it was not possible to directly link the alarm rate with the shuttle reliability and availability data.

Reflecting on the overall impact of the value improvement model, the researcher realises there was an opportunity missed to focus on the financial value adding contributions of all the interventions made. Perhaps in part, this was because the value improvement model was being developed in parallel to its application, an action research approach. The opportunity to improve the *g*-VIM (Figure 83: Generic Value Improvement Model for Repetitive Processes) through future research must therefore focus on the measures of performance: Efficacy, Efficiency & Effectiveness which are not holistic enough and perhaps adding in a fourth E - Economic impact- would make the application of the model a more viable option for justifying process improvement initiatives. Alternatively, perhaps Efficacy could be absorbed into Effectiveness resulting in Economy, Efficiency & Effectiveness as the measures of performance.