THE DESIGN AND DEVELOPMENT OF A KNOWLEDGE-BASED LEAN SIX SIGMA MAINTENANCE SYSTEM FOR SUSTAINABLE BUILDINGS

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The Design and Development of a Knowledge-Based Lean Six Sigma Maintenance System for Sustainable Buildings

The Design and Development of a Hybrid Knowledge-Based (KB)/Gauging Absence of Pre-Requisites (GAP)/Analytic Hierarchy Process (AHP) Model for Implementing Lean Six Sigma Maintenance System in Sustainable Buildings' Environment

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ABSTRACT

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Thesis Title: The Design and Development of a Knowledge-Based Lean Six Sigma Maintenance System for Sustainable Buildings

Sub-title: The Design and Development of a Hybrid Knowledge-Based (KB)/Gauging Absence of Pre-Requisites (GAP)/Analytic Hierarchy Process (AHP) Model for Implementing Lean Six Sigma Maintenance System in Sustainable Buildings' Environment

Keywords: Knowledge-Based Expert System, AHP, Lean Six Sigma, Building Maintenance, Sustainability.

The complexity of sustainable building maintenance environment requires managers to define and implement appropriate quality benchmark system suitable for this function. Lean Six Sigma (LSS) is one of the most effective process improvement and optimization philosophy that maintenance organisations can implement in their environment. However, literature review has shown that 90% of failures in LSS implementations are due to lack of readiness to change, the unawareness of the required benchmark organisation capabilities, and improper control of priorities.

The contribution of the current research approach is in developing a hybrid Knowledge-Based (KB)/GAP/AHP System, consisting of three stages (Planning, Designing and Implementation) and containing over 2500 KB rules. The KB System can assist the decision-makers in identifying the obstacles behind the organisation readiness to change into a benchmark LSS maintenance environment. Thus the KB System will be used to achieve benchmark standards by determining the gap existing between the current environment and the benchmark goal, and then suggest a detailed plan to overcome these hurdles in a prioritised and structured manner, thus achieving cost benefits.

To ensure its consistency and reliability, the KB System was validated in three Oman-based maintenance organisations, and one published case study for a UK-based organisation. The results from the validation were positive with the System output suggesting list of top priorities and action plans for achieving benchmark LSS standards for these organisations. The research concludes that the developed KB System is a consistent and reliable methodology for assisting decision-makers in designing, planning, and implementing LSS for benchmark sustainable building maintenance.

Supervisors: Prof. M. Khurshid Khan, and Dr. J. Eduardo Munive-Hernandez

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LIST OF ABBREVIATIONS

AHP	Analytic Hierarchy Process
AI	Artificial Intelligence
AM	Application Manager
ANN	Artificial Neural Network
ASQ	American Society for Quality
BB	Black Belt
BDN	Building Diagnosis Navigation
BIM	Building Information Modelling
BM	Building Maintenance
BOMA	Building Owners and Managers Association
BP	Bad Point
BQ	Brain Quotient
BREEAM	Building Research Establishment Environmental Assessment Methodology
BSI	British Standards Institution
CAP	Credit Assignment Path
CBM	Condition Based Maintenance
CBR	Cased Based Reasoning
CIBSE	Chartered Institution of Building Services Engineers
CM	Corrective Maintenance
CMMS	Computerised Maintenance Management System
COPQ	Cost of Poor Quality
CR	Consistency Ratio
CSF	Critical Success Factor
CSI	Construction Specifications Institute
CTQ	Critical To Quality
DIKW	Data, Information, Knowledge and Wisdom framework
DL	Deep Learning
DMAC	Define, Measure, Analyse, and Control
DMAIC	Define, Measure, Analyse, Improve, and Control

DPMO	Defects Per Million Opportunities
DOE	Design of Experiment
EFQM	European Foundation for Quality Management
EI	Employee Involvement
ERP	Enterprise Resource Planning
ES	Expert System
ESDLC	Expert System Development Life Cycle
FAME	Financial Analysis Made Easy
FBS	Frame Based System
FL	Fuzzy Logic
FM	Facility Management
FMEA	Failure Mode and Effect Analysis
FNN	Feed-Forward Network
GA	Genetic Algorithm
GAP	Gauge Absence Prerequisites
GB	Green Belt
GHCR	General Hospital of Ciudad Real
GP	Good Point
HRD	Human Resource Development
HVAC	Heating, Ventilation, and Air Conditioning
ICT	Information and Communication Tools
IMS	Intelligent Manufacturing Systems
IOM	Immediate Opportunistic Maintenance
IQ	Intelligence Quotient
IQA&EQMs	International Quality Awards and Excellence Quality Models
IQF	International Quality Federation
ISO	International Organization for Standardisation
JIT	Just In Time
JSBC	Japan Sustainable Building Consortium
KBS	Knowledge Base System
KPI	Key Performance Indicator

Lean6-SBM	Lean Six Sigma Sustainable Building Maintenance
LEED	Leadership in Energy and Environmental Design
LM	Lean Maintenance
LSS	Lean Six Sigma
MBB	Master Black Belt
MBIS	Mandatory Building Inspection Scheme
MBNQA	Malcolm Baldrige National Quality Award
MEP	Mechanical, Electrical, and Plumbing
QGMMF	Queensland Government Maintenance Management Framework
MoD	Ministry of Defence
MP	Manufacturing Process
OEE	Overall Equipment Efficiency
OHSAS	Occupational Health and Safety Assessment Specification
OJT	On-the-Job Training
OM	Opportunistic Maintenance
PC	Problem Category
PdM	Predictive Maintenance
PL	Predicate Logic
PM	Preventive Maintenance
PS	Performance Score
PV	Priority Vector
QFD	Quality Function Deployment
QMS	Quality Management System
QSAS	Qatar Sustainability Assessment System
RCA	Root Cause Analysis
RIBA	Royal Institute of British Architects
RMAA	Repair, Maintenance, minor Alteration, and Addition works
RNN	Recurrent Neural Network
ROA	Return on Asset
ROE	Return on Equity
ROI	Return on Investment
SA	Simulated Annealing

SBM	Sustainable Building Maintenance
SMED	Single-minute Exchange of Dies
SMEs	Small and Medium-sized Enterprises
SPC	Statistical Process Control
SQU	Sultan Qaboos University
SQC	Statistical Quality Control
TBM	Time Based Maintenance
TPM	Total Productive Maintenance
TPS	Toyota Production System
TQM	Total Quality Management
VOB	Voice of Supplier
VOC	Voice of Customer
VOE	Voice of Employee
VOP	Voice of Process
VSM	Value Stream Mapping
3Cs	Commitment, Culture, and Communication
4Ps	Planning, People, Processes, and Performance
5S	Sort, Set in order, Shine, Standardise, and Sustain

LIST OF PUBLICATIONS

Journal Papers:

Aldairi, J., Khan, M. K., & Munive-Hernandez, J. E. (2017). Knowledge-based Lean Six Sigma Maintenance System for Sustainable Buildings. *International Journal of Lean Six Sigma*, *Emerald*, 8, 109-130.

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Conference Papers:

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Aldairi J., Khan M.K., & Munive-Hernandez J. E. (2015). A Conceptual Model for a Hybrid Knowledge-based Lean Six Sigma Maintenance System for Sustainable Buildings. In *Proceedings of the World Congress on Engineering (WCE)*, London (Vol. 2), pp. 939-944.

CHAPTER 1

Introduction

1.1 Background

This chapter defines the main aim and objectives of this research, which focuses on the integration of Lean Six Sigma (LSS) in a Sustainable Building Maintenance (SBM) environment. This will be achieved by developing a hybrid Knowledge-Based System (KBS), which will be integrated later with Gauge Absence Prerequisites (GAP) and Analytic Hierarchy Process (AHP) methodologies. The significance and novelty of this research will be presented, and its potential contribution will be highlighted.

As part of the facility management processes, Building Maintenance (BM) plays an important role since it deals with uncertain factors affecting the performance of the organisation (Lind and Muyingo, 2012). Maintenance is defined by BSI (1993: 30) as *“the combination of all technical and associated administrative actions intended to retain an item in, or restore it to a state in which it can perform its required function”*. According to Mishra and Pathak (2012), maintenance is the recurring and routine process that keeps the asset in normal condition while achieving the expected performance or service. This leads to the requirement for having maintenance performance measurements for buildings. Zawawi et al. (2011) insisted that performance in maintenance operations management must be analysed and reviewed continually in order to achieve high service quality.

Mishra and Pathak (2012) highlighted that the main objective of the maintenance system is achieving maximal availability with minimal cost. They proposed that this objective can be obtained by optimising the other sub-objectives (e.g. enhancement of performance level, maximising operational efficiency, eliminating future defects), which are illustrated in Figure 1.1.

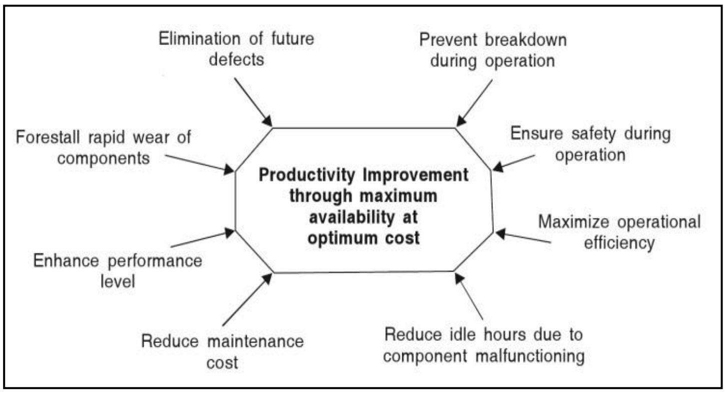


Figure 1. 2 Maintenance objectives, adopted from Mishra and Pathak (2012)

Lam et al. (2010) highlighted that maintenance activities represent 50% of overall construction project activities in Britain. They conducted a qualitative survey in Hong Kong targeting the issues behind managing maintenance projects. Their findings revealed that the most significant factors are lack of expertise, insufficient communication, constraints of existing buildings, short duration, and fragmented nature.

Practically, maintenance-oriented organisations are spending a huge portion of their annual budgets in auditing and measuring their quality performance by hiring experts who, in many cases, are difficult to find (Macek and Dobiáš, 2014). According to Wood (2005), the global market is on the way to spending £28 billion per year in BM and repair compared to a £10 billion investment in new buildings by the year 2035.

According to Dhillon (2006) and Fraser (2014) maintenance represents 60% to 75% of a large system or product’s lifecycle costs. This will automatically create a challenge for maintenance management in validating an asset performance and allocating the required funds. Therefore, one of the main reasons behind weaknesses in maintenance management systems is a lack of experience in priority control as a result of imprecise information obtained. Salata et al. (2014) noted that high maintenance expenses occur because of insufficient reliability, which leads to frequent decline of service given.

Lind and Muyingo (2012) stated that public organisations have increased their focus on BM because of huge investments in related infrastructure (e.g. hospitals and schools). However, different building components have different rates of deterioration, which in fact must have a scale of prioritisation in order to fulfil the main requirements to satisfy customer expectations Olanrewaju and Abdul-Aziz (2015).

According to Horner et al. (1997), BM can be divided into three main strategies: condition-based, corrective, and preventive maintenance (PM). They elaborated that whole-building components shall be categorised under these strategies based on Failure Mode and Effect Analysis (FMEA). This will drive to further investigate the effect of such quality tools or alternatives on obtaining the required standard of BM.

Flores-Colen and de Brito (2010) asserted that building failures could occur because of failure in design, failure in construction, failure in maintenance, failure in quality of materials, or failure of misuse. From a practical perspective, failure in BM can be divided into two parts: maintenance that is performed incorrectly and maintenance that is not attended at all. Almarshad et al. (2010) insisted that one of the major issues in BM is the unavailability of original operation and maintenance documents related to particular construction projects. This definitely will lead to waste of time in fault diagnosing and therefore additional expenses. This evidence was proved by Frank et al. (2015) when they investigated the indispensability of clear operation and maintenance manuals for sustainable buildings.

1.2 Problem Statement

Currently, maintenance management systems are still not practised in a professional way (e.g. maintenance schedules are not implemented on time, and priorities are difficult to identify) owing to lack of maintenance management skills and execution experience, which leads to poor impacts and crucial negative effects on facilities that must be maintained (Zawawi et al., 2011; Suffian, 2013). However, these two studies have focused only on identifying critical success factors that can improve customer satisfaction and sharing the experience of BM management. On the other hand, Zulkarnain et al. (2011) took this idea further by specifying the factors for selecting proper maintenance systems, considering certain facts such as building material lifecycle and services installations.

The main objective of any maintenance organisation is to maximise asset performance and optimise maintenance resources in order to achieve maximal production and hence a high return (Jardine and Tsang, 2013). However, these objectives cannot be achieved without strengthening the missing link between maintenance and quality (Mishra and Pathak, 2012). The studies conducted by Ahuja and Khamba (2008), Simões et al. (2011), Mast and Lokkerbol (2012), and Jardine and Tsang (2013) reviewed the use of Six Sigma, Just In Time (JIT), Total Quality Management (TQM), and Total Productive Maintenance (TPM) in maintenance and quality applications. These approaches have been successfully implemented in the manufacturing production sectors. However, for better implementation, and because of various concepts and strategies in the BM business, some modifications must be applied.

The complexity of a sustainable BM environment and its related activities compel the top management level to determine a standardised universal performance audit that can be applied to all concerned departments. Currently, as part of performance auditing, quality management approaches vary from one organisation to another. This implies that much research has focused on measuring maintenance performance (Silva and Falorca, 2009; Olanrewaju et al., 2011; Wang et al., 2013; Salata et al., 2014) and continuous process improvement (Dukić et al., 2013; Suffian, 2013). However, these research initiatives have not assessed the performance of implementing integrated Lean and Six Sigma tools in BM. In Practice, BM facilitators' approaches in measuring their maintenance quality management vary from regular inspections to advanced monitoring of Key Performance Indicators (KPI), using software applications such as Computerised Maintenance Management Systems (CMMS) and Enterprise Resource Planning (ERP).

Olanrewaju et al. (2011) claimed that BM management in Malaysia is not performing well based on research literature background and numerous media complaints. Jardine and Tsang (2013) justified the importance of implementing continuous improvement into a maintenance excellence hierarchy structure by focusing on people and assets. However, the maintenance research area is still in need of further development methods with regards to improving lack of benchmarking and performance measurements (Singh et al., 2016). Technically, it is obvious that in order to achieve high equipment efficiency, some major losses must be addressed and eliminated (e.g. setup and adjustment, equipment failure, minor stoppage, idling, reduced speed, and process defects).

According to George et al. (2003), the cost of waste within the service industries (e.g. healthcare, banking, engineering) is 30–80%. Milana et al. (2014) investigated this waste in the maintenance area and reported that unnecessary repairs or inspections definitely lead to increases in budgets. This indicated that maintenance processes are filled with non-value-adding steps that require continuous improvement. Therefore, there is a need to examine the integration of Lean with Six Sigma in such environments due to the fact that Six Sigma will address process control and customer focus with relevant tools, and Lean will accelerate the process by reducing the lead time through elimination of waste (Albliwi et al., 2014).

According to Pulselli et al. (2007), sustainable buildings have the following features: inflows of most materials and energy, use of renewable materials, and less impact on natural resources. Ding (2008) discussed the importance of comprehensive environmental building assessment methods, which assess building performance based on the triple bottom line of sustainability pillars (social, environmental, and economics aspects) and reflected the sustainability concept in the context of BM.

Findley et al. (2004) and Dewlaney and Hallowell (2012) identified and described risk mitigation strategies in sustainable construction. Omar et al. (2013) examined the safety issues behind implementing PM in sustainable buildings. For example, they raised the points of maintaining a green slippery roof without protection and the lack of a guard rail to support technicians who maintain skylights.

A key aspect of current thinking adopted is the use of green maintenance in Green Buildings. Green Building construction aims to minimise the total environmental impacts of this industry (Eichholtz et al., 2013). Therefore, it is possible to notice the concept of Green Building shifting towards the concept of sustainability, specifically environmentally sustainable buildings. This might justify the frequent use of the word *green* in the context of sustainable building.

Approximately 51% of the engineers, architects, owners, contractors, and consultants who participated in a study anticipated that more than 60% of their work would lie in green technology construction by the year 2015 (Bernstein et al., 2013).

Therefore, it is quite essential to further develop an optimised method that could help facilities management of the sustainable buildings in reducing cost while performing a high quality of maintenance services.

1.3 Research Project Aim

The research is seeking to propose an effective decision making tool that can help in maximising the benefits from implementing Lean Six Sigma (LSS) in maintenance environment for sustainable buildings. Therefore, the aim of this research is to design and develop a hybrid Knowledge-based (KB) System for integrated LSS linked to Maintenance perspective in Sustainable Building context (Lean6-SBM). The System will incorporate GAP and AHP as a methodological approach to enhance the decision making process. Additionally, the research is intended to understand and analyse this industry, acquire the critical knowledge, and recommend the appropriate action agendas to be taken for the future improvement of the KB Lean6-SBM.

1.4 Research Objectives

The problems related to building maintenance have motivated this research to focus on a PM of a SBM. It has been found from the literature review that no study attempt to integrate a KB System embedded with both GAP and AHP to facilitate the area of Lean6-SBM environment. The KB/GAP/AHP System was applied in the ISO 9000 Advisory tool (Khan and Hafiz, 1999), supply chain management (Udin et al., 2006), performance measurement systems (Khan and Wibisono, 2008), lean manufacturing (Nawawi et al., 2008), low volume automotive (Mohamed and Khan, 2011), and maintenance strategy and operation (Milana et al., 2014). In order to achieve the aim of this research, the main objectives can be derived as the following:

a. To conduct a literature review in the fields of SBM, LSS, and Artificial Intelligence (AI) concepts and methodologies. The outcome will be formulated to develop a Knowledge-Based Lean Six Sigma for SBM (KB Lean6-SBM) System.

b. To design a Knowledge Base (KB) model using GAP and AHP. The KB Lean6-SBM model will integrate the quality and maintenance parameters at different Levels of the KBS to fulfil the requirements of the final product.

c. To convert the KB Lean6-SBM model into a hybrid (the integration of AI, LSS, and SBM) conceptual framework. This will be structured in a decision Level hierarchy in which the KPIs are identified for each Level. The originality of this integration can be highlighted in Figure 1.2 which represents the research gap derived from the literature review.

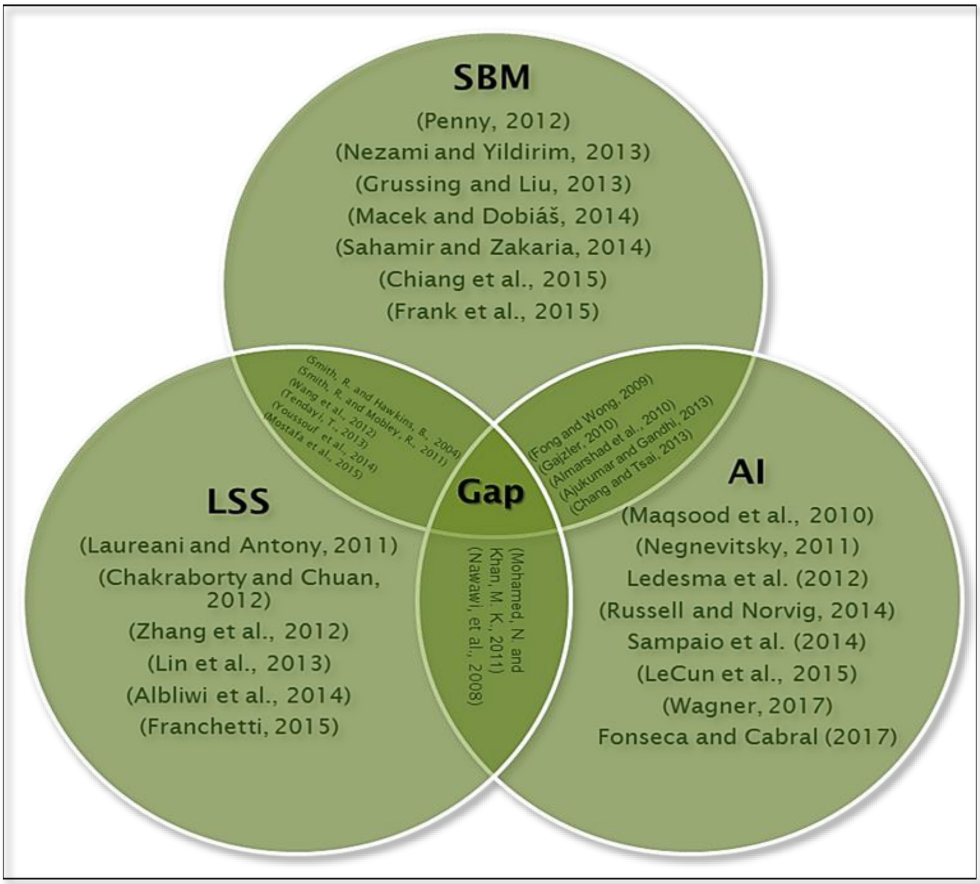


Figure 1. 3 The Research Gap

d. To develop the KB rules, followed by applying GAP and AHP methodologies. These two methodologies will diagnose the weak points in the existing system through benchmarking criteria against the desired situation and work to prioritise the recommended solutions.

e. To validate and refine the hybrid KB Lean6-SBM model. The validation process will take place through implementation in a real SBM environment in order to ensure conformance of the KB model with experts' expectations and user satisfaction (Nawawi et al., 2008). The feedback from the validation process will be used to refine the KB Lean6-SBM System with the aim to maximise its reliability and consistency.

f. To conclude the work addressed and highlight some recommendations for future research.

1.5 Research Contribution

In order to achieve the main objectives of this research, a SBM management taxonomy will be integrated with a LSS (an advanced quality concept that will be refined to suit the targeted environment). However, there will be a need to simplify the process owing to the complexity of many variables in SBM. The impact of the alternatives in a multi-criteria problem cannot be quantified accurately and thus will affect the decision making (Lo et al., 2000). Therefore, a strong multi-criteria decision making tool will be used to deal with such complexity. For this purpose, AHP is selected to be integrated with the new system.

Thus, the significance of this research is to advance the use of a hybrid KB/GAP/AHP System to develop Lean6-SBM. This approach is new for the specified field and will assist in identifying issues pertaining to quality while implementing different maintenance strategies in the sustainable building context. It will go further to suggest optimal and semi-optimal solutions based on experts' knowledge and functional priorities.

This research intends to develop a universal benchmark Lean6-SBM that can help in this regard by using qualitative and quantitative knowledge analysis techniques. Therefore, the novelty of this research is to extend the use of KBS with GAP and AHP to develop an integrated KB Lean6-SBM to be used in a SBM environment. This will fulfil the requirements of analysing quality problems and recommend proper solutions according to international best practices. The System will benchmark the existing situation with the ideal framework derived from extensive evaluation of international quality concepts that can fit in the SBM sector, which will be followed by recommending solutions to fill the identified gaps.

Thus, the research will deliver an effective decision support system that will assist top management, quality/maintenance managers, and practitioners in the SBM sector to prioritise and monitor their performance and hence increase their productivity. In addition, the System will integrate LSS and a readiness evaluation framework to facilitate the implementation of this System.

1.6 Research Approach

The approach of this research is a mixed (combination of research methods) of literature review with knowledge acquisition from experts and relative documents, followed by a research design model of a hybrid KB Lean6-SBM and further development of the conceptual framework. The verification process has been conducted throughout the KB design and development stages. On the other hand, the validation process is performed for the overall System through published and real industrial cases.

1.6.1 Research Road Map

The pictorial shown in Figure 1.2 illustrates the road map steps of this research. The road map (approach) flow is structured to start with a comprehensive literature review and analysis of knowledge acquired from multidisciplinary fields related to AI, LSS, and SBM. This is followed by the design of the KB Lean6-SBM model, which will be verified, and refined through experts' feedback, and relative documents.

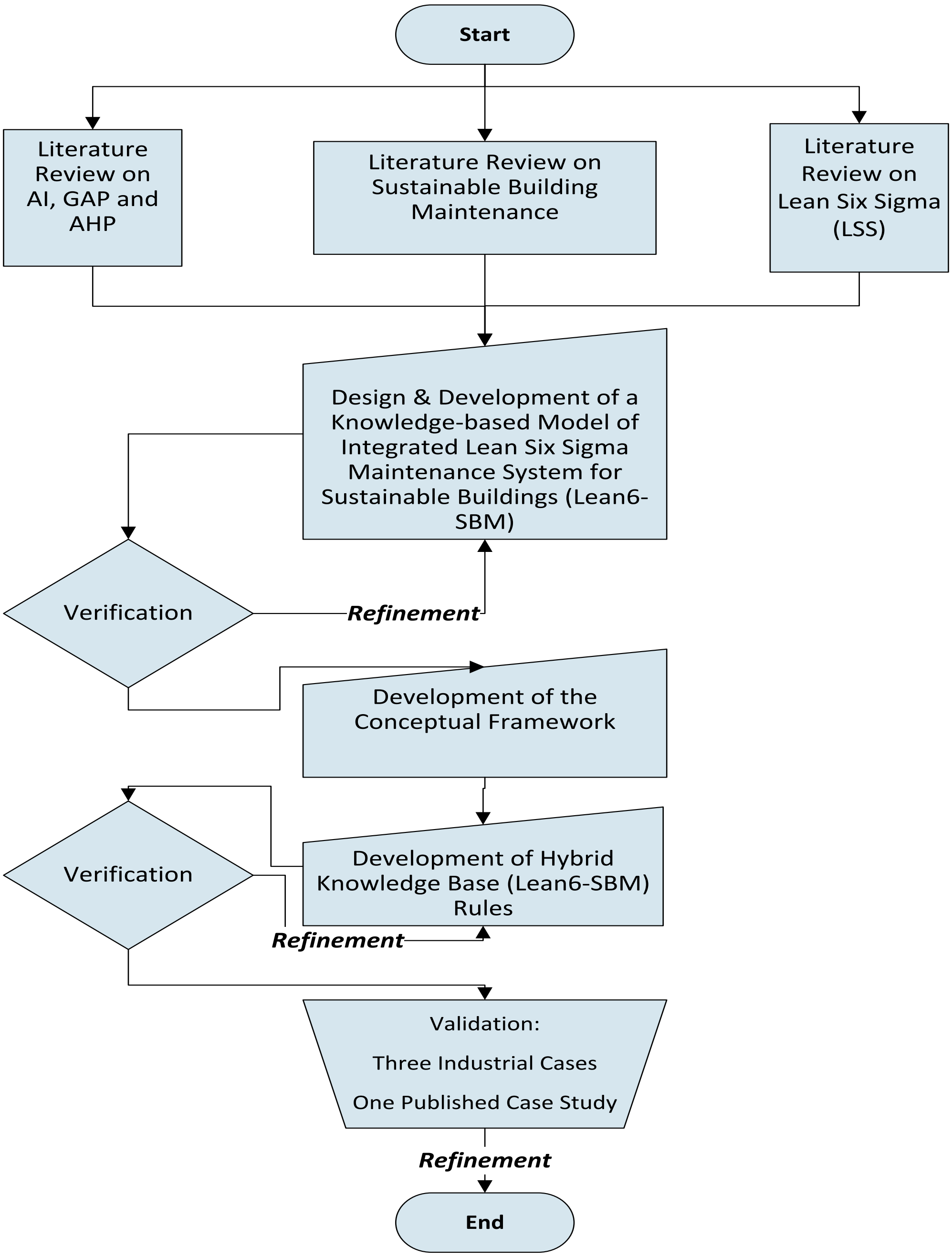


Figure 1. 4 Research Road Map

The detailed development of the conceptual framework will come next and be structured in two stages: the first stage drives the strategic Level of KB Lean6-SBM, whereas the second stage focuses on the KB Lean6-SBM operational Level. The primary data acquired for the detailed development of KB Lean6-SBM System will be based on standard maintenance strategies of certified sustainable buildings. Three of the sustainability oriented organisations will be involved in the development and validation of the model to show the actual quality practise in the maintenance process. These are Armed Force Hospital Engineering Services (Oman), Bahwan Engineering Services, and Technical Trading Company.

1.6.2 Conceptual Development

This research proceeds with the study of the current methods for improving quality in SBM by performing a literature review on the areas of AI, LSS, and SBM. The design and development of KB Lean6-SBM will involve AHP and GAP, which will be embedded in the literature review.

The development of a conceptual framework for KB Lean6-SBM will be supported by the published articles on KB, GAP, and AHP. All factors that are critical to develop the new Lean6-SBM model will be revised and analysed using GAP and AHP. There is no evidence in the literature that a combination of KB, GAP, and AHP has been utilised as an approach in the field of managing LSS in SBM.

According to Mohamed and Khan (2012), GAP analysis is used to determine the gap between prerequisites using structural and hierarchical formats. On the other hand, AHP is widely applied as a powerful tool to weight factors and prioritise decisions in addition to confirming the integrity and correctness of those factors that are made by the user (Khan and Wibisono, 2008). This research will extend the methodology of using GAP in line with the AHP hierarchical structure, which has been proved in previous studies (Khan and Wibisono, 2008; Nawawi et al., 2008; Mohamed and Khan, 2012; Milana et al., 2014) to be a powerful tool in overcoming the inconsistency of problem evaluation due to complex alternative factors.

After verifying the conceptual framework, the Lean6-SBM model will be developed into the KB System. This stage will focus on applying LSS at both strategic and operation Levels based on selected elements of SBM taxonomy, which will lead to produce the KB Lean6-SBM System. The KB development process includes generating a rule-based system that will be verified and refined continuously till the completion of the operational stage. Finally, the KB Lean6-SBM System will be validated through a published case study and three real industrial applications. The validation of the KB Lean6-SBM System in real applications is essential, because it will measure the practicality of this type of a benchmark assessment in the SBM environment.

1.7 Thesis Outline

This thesis consists of eight chapters. Chapter 1 contains the background to the research, statement of the research problem, the project aim, the research objectives, the research contribution, and the research approach.

Chapter 2 presents the literature review of the SBM and the relation with quality. It explains the maintenance business excellence, maintenance strategies, building construction, sustainable buildings, the demand for maintenance in construction projects, SBM taxonomy, and the relation of the SBM and quality. This chapter is crucial as it represents the base of the knowledge acquisition for the SBM environment.

Chapter 3 presents the literature review of LSS, starting by describing quality evolution, TQM, models of TQM, Lean management, tools and techniques in LSS, and previous studies of LSS conducted in building maintenance. Again, this chapter is very important with regards to the knowledge acquisition in the field of LSS.

Chapter 4 presents the literature review of Concepts and Methodologies. It demonstrates a comprehensive overview of data, information, knowledge, and wisdom (DIKW), DIKW arguments, intelligence, human intelligence, Artificial Intelligence (AI), AI concepts and methodologies, the applications of AI in building maintenance, and finally, an overview of the GAP and AHP methodologies.

Chapter 5 proposes the conceptual framework of the integrated LSS maintenance system for sustainable buildings. It starts by presenting the design model of the system that describes planning, designing, and implementation stages. This is followed by the development of the conceptual framework, the structure of the KB Lean6-SBM System, and finally, the design method of the hybrid KB/GAP/AHP Lean6-SBM System.

Chapter 6 describes in detail the development of the KB Lean6-SBM System. In the strategic decision phase, *Level 0: Organisation Environment, Level 1: Organisation Business Perspective, Level 2: Organisation Resources*

Perspective, and Level 3: LSS Readiness for Change had been developed. While in the operational decision phase, *Level 4: LSS Sustainable Building Maintenance Perspective*, and *Level 5: DMAIC Implementation* were developed. Both phases have covered the key aspects of the KB Lean6-SBM development.

Chapter 7 demonstrates the details of the validation process of the KB Lean6-SBM. It contains the results' discussion of the validation conducted in three real industries and one published case study.

Finally, Chapter 8 concludes this research by highlighting the achievement towards the research objectives, advantages and limitations of the KB Lean6-SBM, and proposing recommendation for future research.

1.8 Summary

This chapter has described the research background and problem statement. This includes some literature and methodologies that will support the structure of this research. It enhances the need for a hybrid KBS for implementing LSS in a SBM context. A detailed statement of the aim and objectives of the research has been declared. The significance and novelty of the proposed approach and the road map of the research has been given and presented systematically. The next chapter will discuss the literature review of sustainable building maintenance.

CHAPTER 2

Literature Review of Sustainable Building Maintenance

2.1 Introduction

The dramatic transformation of buildings' architectures towards green technology becomes a general practice. Green or Sustainable Buildings aim to minimise the total environmental impacts in construction industry (Eichholtz et al., 2013) which keep them different from the traditional approach. However, this has enforced facilities management's providers to amend the current maintenance strategies to fit with that aim. Although, maintenance organisations are spending a huge portion of their annual budgets in auditing and measuring their quality performance (Macek and Dobiáš, 2014), there is always a gap to reduce such amount. This chapter will introduce some guidelines to achieve maintenance business excellence as well as highlight maintenance strategies and their applicable schemes to maintain Sustainable Building construction. Next, the chapter will investigate the key indicators in maintenance performance measurement. It will also review the current maintenance practice in sustainable buildings, followed by identifying the best suitable building maintenance taxonomy that could fit into that environment. Finally, it will justify the need for a comprehensive quality approach in such fields through a contemporary literature review.

2.2 Maintenance Business Excellence

Maintenance is described in British Standard Institute (BSI, 2010: 3) as the "*combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function*". Accordingly, CIBSE Guide M states that maintainability is the ability of a product to be restored or retained to a specific condition by skilled personnel using prescribed resources and procedures. Moreover, Silva and Falorca (2009: 3250) declared that "*A maintenance plan is a group of specifications accomplished in the context of the maintenance process, being designed to* *program preservation actions*". In order to reach high maintenance efficiency and productivity, the following parameters must be achieved (Jardine and Tsang, 2013):

- High level of serviceability
- Efficient supply chain management
- Reasonable investment in new assets and maintenance costs within budget
- Smooth operation of plant and equipment up to manufacturing standards
- Competent and motivated stakeholders

2.3 Maintenance Strategies

Based on BSI (2010), maintenance strategy is a management approach to achieve the maintenance objectives. Simões et al. (2011) conducted a survey targeting published cases in maintenance performance measurement from 1979 to 2009. They highlighted that there is a difference between maintenance performance efforts based on systematic organisational perspective and those based on a limited budget perspective. Figure 2.1 emphasises the differences in the role of maintenance between organisations starting with closed-system manufacturing organisations, which tend to have a standalone operational function, and ending with today’s open-system organisation, which utilises the maintenance role as a strategic competitive approach. This approach will tend to retrieve the information required from integrated benchmarking practices.

According to Chartered Institution of Building Services Engineers CIBSE-Guide-M (2014), building maintenance can be divided into two main categories - planned and unplanned - which are formed based on maintenance strategies. Unplanned maintenance includes the concept of “run to failure” and is known as reactive maintenance. According to Sullivan (2010), more than 55% of maintenance resources and activities are considered to be reactive. On the other hand, the planned maintenance is divided into two sub-categories: before the fault and after the fault.

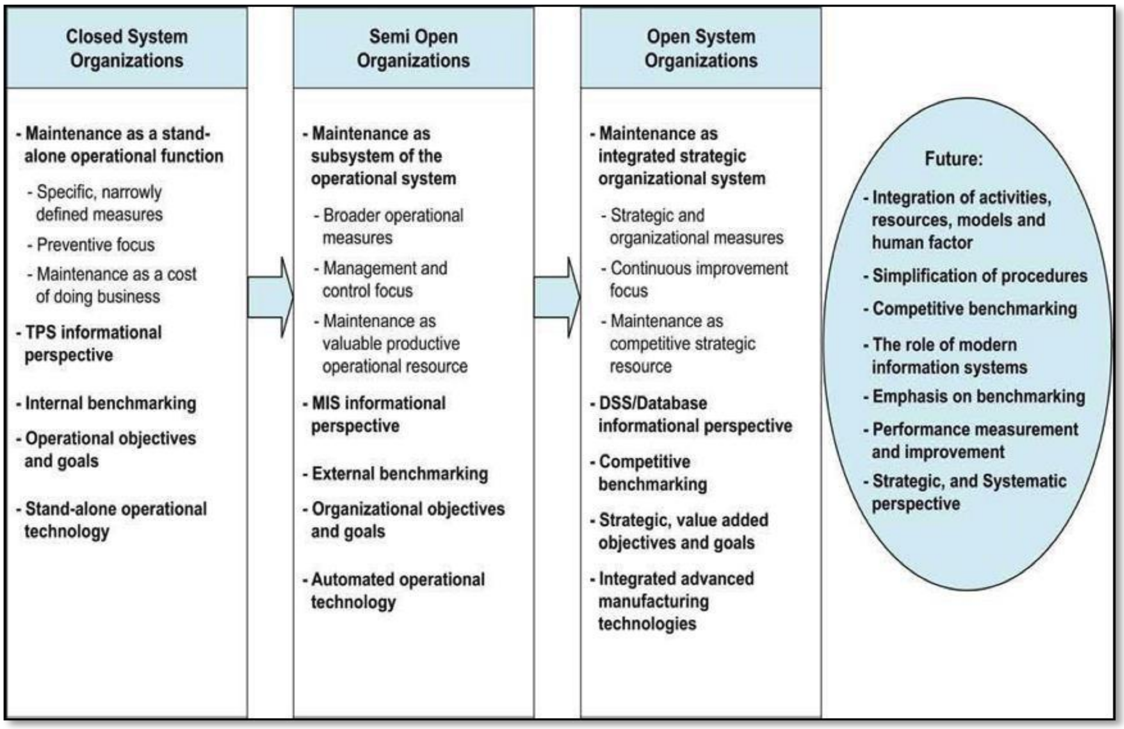


Figure 2. 1 Maintenance activities evolution and organisational roles, adopted from Simões et al. (2011)

For this research, the most applicable building maintenance strategy is adopted from Lind and Muyingo (2012) and can be illustrated as shown in Figure 2.2. This strategy is categorised into two types of maintenance: CM and PM. Corrective action takes place after a fault occurs which leads to increase in downtime and maintenance cost, whereas preventive action is prior to occurrence of the failure and contributes to minimise downtime and maintenance cost (Ahmad and Kamaruddin, 2012). This research will specifically focus on planned PM strategy.

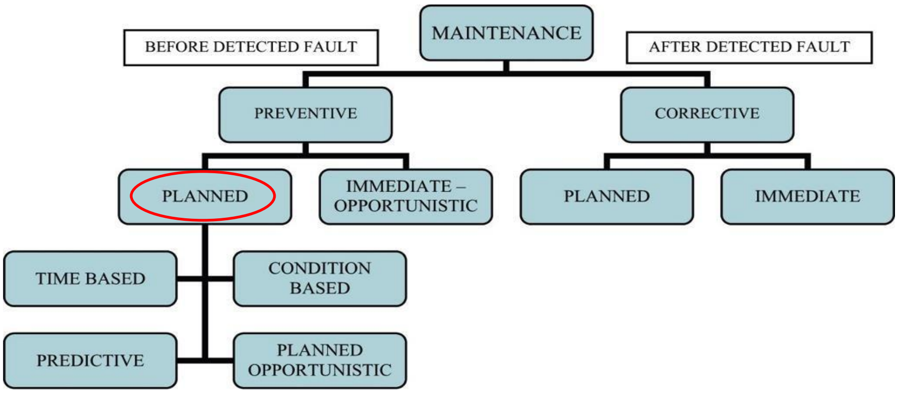


Figure 2. 2 Building maintenance strategies, adopted from Lind and Muyingo (2012)

2.3.1 Corrective Maintenance (CM)

CM involves remedial action taken as a consequence of defects found during unplanned or planned maintenance to return an asset to its normal condition. This might seem to be encountered in the role of reactive maintenance; however, the main action to be taken in reactive maintenance is basically CM.

CM is scheduled according to the time required for shutdown; hence, it can be performed during (immediate) or sometime after (planned) the inspection process (Peters, 2006). It is obvious from practice and theories (Sullivan, 2010), that PM is not able to overcome all types of failures, which justifies the widespread adoption of CM in real world applications.

2.3.2 Preventive Maintenance (PM)

PM is a strategy based on periodic inspection of an asset in order to check and diagnose the functionality of its components and related subsystems. According to Peters (2006), PM assists in keeping an asset working per its expected performance until the next inspection due date or planned repair. Nezami and Yildirim (2013) described PM as basically time-based (e.g. calendar or age wise) through task scheduling without regard to the asset’s condition. However, some defects might be discovered during an inspection (of planned work order), which should be planned accordingly; this case is known as CM. According to Mays (2015), there are five steps for successful PM strategy; conducting a review (for assets, procedures, and people), establishing standardised procedures, creating an improvement plan, leveraging technology (e.g.; Computerised Maintenance Management System (CMMS)), and applying a 10% rule variation of time frequency. She claimed that experts recommend an improvement plan of PM to be revised in 3-year timeline.

2.3.2.1 Opportunistic Maintenance (OM)

This approach of concept considers the maintenance done due to rise of an opportunity of cost effective way. This is occurred in PM scheduled activity, when rescheduling of another activity becomes very important, to take the opportunity of scaling-up the current activity (Lind and Muyingo, 2012). In other words, the OM takes place when a PM of certain component is carried out due to the opportunity raised from having a failure in other component. This will lead to achieve the objective of optimising the maintenance cost and reliability (Ab-Samat and Kamaruddin, 2014). This type of maintenance approach can be immediate or planned, depends upon the situation and criticality of the asset.

2.3.2.2 Time Based Maintenance (TBM)

TBM or scheduled maintenance is a PM where the tasks are scheduled based on frequency of time, regardless of the current condition of an item (Lind and Muyingo, 2012). According to Ahmad and Kamaruddin (2012), this type of periodic method is designed based on failure time or used time data. They claim that it is only effective for the items that have constant deteriorating state, where the failure rate is increased constantly. However, the main practical issue is in accurate recording of the failure/usage rate.

2.3.2.3 Condition Based Maintenance (CBM)

CBM is a PM where the inspection is conducted for the item in regular basis and it is replaced or serviced based on the observation under certain condition (Lind and Muyingo, 2012). Shin and Jun (2015) described that the focal point of CBM is in monitoring the equipment degradation in addition to diagnosing and detecting faults which in fact, increase the safety assurance within the work environment. This will enable to have more efficient planned maintenance by decreasing the TBM intervals and eliminating unnecessary inspections (Chen et al., 2012). However, nearly 30% of maintenance equipment is not benefiting from PdM/CBM, due to the prerequisites of high investment in installing a monitoring system that can help in decision-making (Hashemian and Bean, 2011).

2.3.2.4 Predictive maintenance (PdM)

Peters (2006) claims that PdM is basically a condition-based method in which some output of the asset must be measured, analysed, and compared to predefined limits or baseline and remedial actions are planned accordingly. Therefore, corrective actions might be taken immediately after PdM analysis, which intersects with PM in this regard. Practically, PdM has the advantage where it is normally processed while the equipment/asset is loaded or in production condition.

However, in most applications, assets must be offloaded in order to tackle the PM schedule.

2.4 Measurement of Maintenance Performance

Today, organisations are facing pressure to continuously improve the maintenance cost effectiveness, which in fact, will add value to the internal operation and offer more innovative services to the customers (Kumar et al., 2013). They have concluded from the literature reviewed that the common used maintenance Key Performance Indicators (KPIs) can be categorised into leading indicators and lagging indicators (Figure 2.3). Leading indicators include measuring the efficiency of work order identification, work order planning and scheduling, and work order execution. On the other hand, lagging indicators include measuring equipment effectiveness, maintenance cost effectiveness, and number of safety and environment incidents.

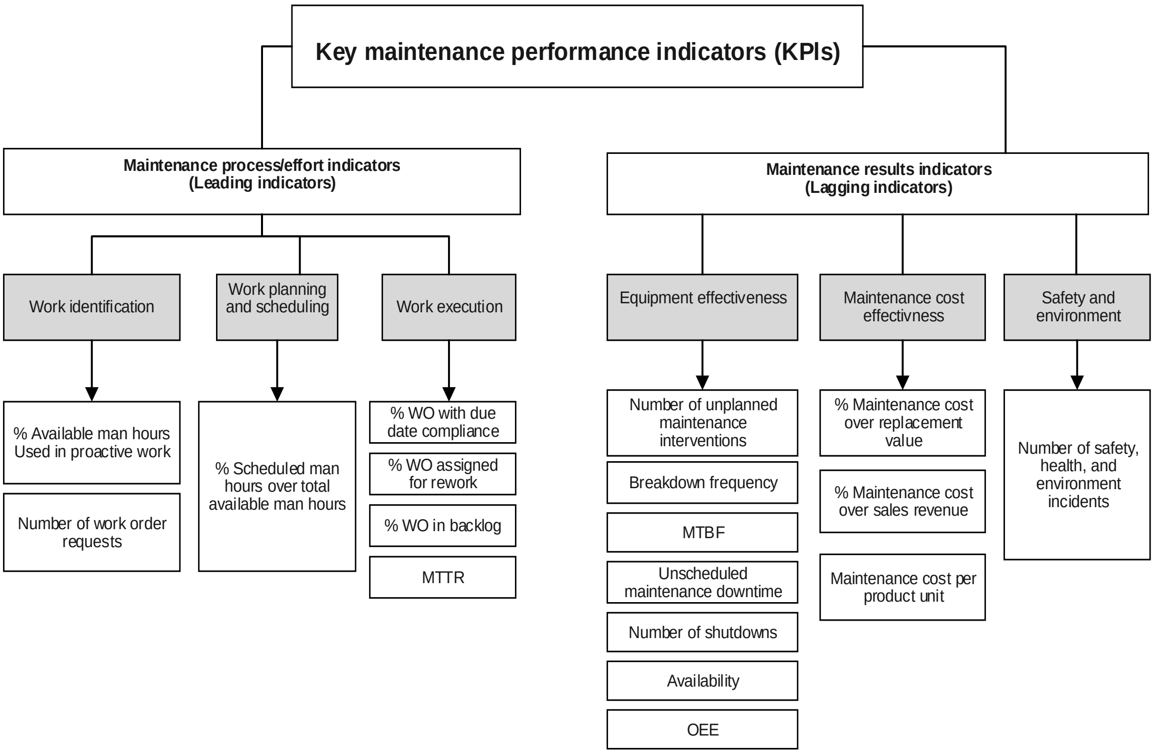


Figure 2. 3 Maintenance Key Performance Indicators, adopted from Kumar et al. (2013)

Based on Muchiri et al. (2011), leading indicators record if the maintenance tasks are being executed that will lead to the expected results. Whereas, lagging indicators record whether those results have been achieved.

2.5 Sustainable Building Maintenance (SBM)

This section will investigate the literature reviewed in SBM environment; starting with general overview to buildings' construction, sustainable buildings, demand of maintenance in construction work, and ending with deep analysis in SBM.

2.5.1 Building Construction

Olanrewaju and Abdul-Aziz (2015) categorised the components of any building into nine major elements: foundation, frames (columns, beams, staircases, and floors), windows and doors, internal walls and partitions, external walls, roof structures, painting and finishes, lifts and escalators, and engineering services (e.g. energy supply, communication, drainage system). Simpeh (2013) asserted that any building is composed of five layers:

- Site: surrounding environmental context of a building
- Shell: building structure
- Scenery: components that will be fixed in the shell and fit according to organisational requirements
- Services: ventilation, heating, and cabling of the building infrastructure
- Set: building management

According to Chang and Tsai (2013), the life cycle of any building comprises seven steps: planning, proposing, designing, constructing, operating, maintaining, and demolishing. Liu et al. (2012) implemented the life cycle cost theory into maintenance decision-making of an existing reinforced structure building. Their study has influenced maintenance in terms of reliability and deterioration speed.

It is obvious that the above building components, layers, and life cycle are general for all types of buildings. However, the differences are proportional to the structure complexity of each building, which consequently leads to the need of investigating new building management techniques.

2.5.2 Sustainable Building

The dramatic population increase with the simultaneous increase in living standard requirements have increased the energy demand. The priority in the search for new energy sources has been shifted towards applying new methods that can reduce energy consumption. Therefore, one of the best currently emerging techniques is the orientation into constructing green or Sustainable Buildings (Oxley, 2011).

AboulNaga and Elsheshtawy (2001) described the word sustain to mean preservation of existence, continual maintainability, and long-term productivity. Sustainability is built on assessment tools that apply quantitative performance indicators of a building and rating tools which determine the performance level of that specific building (Ding, 2008). Nezami and Yildirim (2013) introduced a framework that utilises different sustainable metrics (i.e. social, environmental, and economic) in order to select a suitable maintenance policy (e.g. TPM, preventive, condition based, reliability centred, and failure based) for a manufacturing company.

There are many worldwide building sustainability assessment methods. Penny (2012) investigated some of these methods, such as Building Research Establishment Environmental Assessment Methodology (BREEAM), Leadership in Energy & Environmental Design (LEED), Building Owners and Managers Association (BOMA) 360 and Qatar Sustainability Assessment System (QSAS). Penny (2012) insisted that integrating continuous improvement into operation and maintenance is an essential part of any Sustainable Building. According to Oxley (2011), and based on BREEAM, sustainability assessment is divided into two stages: design assessment and post-construction assessment. Each assessment is composed of nine categories, which are Health and Wellbeing, Management, Energy, Water, Land Use and Ecology, Waste, Materials, Transport, and Pollution. In order to achieve BREEAM certification, a building has to pass an assessment based on standardised weightage criteria and credits.

Ding (2008) stated the importance of comprehensive environmental building assessment methods to assess building performance based on environmental pillars and reflect the sustainability concept in the context of building maintenance.

Sahamir and Zakaria (2014) evaluated green assessment criteria for a public Malaysian hospital by benchmarking the existing worldwide Green Building criteria with the Malaysian rating system. The finding represents a starting guide to more consistent green practice in Malaysian hospitals.

On the other hand, Ascione et al. (2013) investigated the energy consumption demand for an HVAC system at a medium-sized hospital in the Mediterranean; such buildings require a high level of microclimate control owing to heat changes and strict set points for required temperature and humidity. The resulting energy savings are reflected back to reductions in pollution and economic feasibility.

Short et al. (2012) proved the resilience of a healthcare medium-rise block building constructed in the late 1960s. Their findings showed that the building will sustain the current changing climate until the 2030s. This was in accordance with the instruction of implementing calibrated dynamic thermal models against measured data from four National Health Service (NHS) hospital buildings based on the national carbon reduction strategy.

2.5.3 Demand of Maintenance in Construction Work

As an example, according to statistics obtained from the “Office for National Statistics”, the line graph shown in Figure 2.4 compares the expenses spent in £billion on construction work (i.e. all work, all new work, and repair and maintenance) in the Great Britain from January 2010 to January 2017. Overall, it can be seen that repair and maintenance and new work were following the same pattern till the mid-2014. Since it reaches the peak in August 2014, the trend of repair and maintenance has declined due to decrease in housing and non-housing repair by 1.1% and 1.6% respectively, with constant increase in new projects. In January 2017, the repair and maintenance account represents 34% of the all new work accounts which put the facilities management organisations in a mode that requires a high attention due to the acceleration in market competition which in fact, caused by the raise of standards in customer satisfaction (Office for National Statistics, 2017).

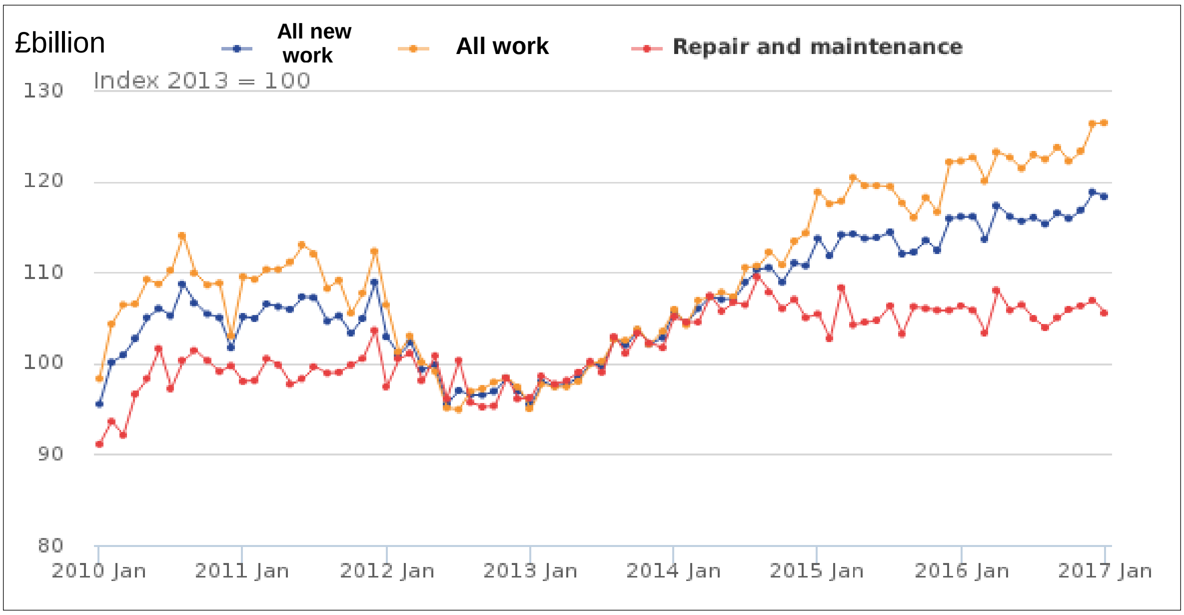


Figure 2. 4 All work, all new work, and repair and maintenance, monthly time series, index prices (2013 = £100 billion), adopted from Office for National Statistics (2017)

In practice, it is well known that any defect in a new construction project has a cause, which might be associated with management, technical factors, or human resources. Sui-Pheng and Wee (2001) classified three main human-related categories that cause defects in project systems:

- Management (e.g. defective document, bad communication, and unanticipated consequences of change)
- Technical factors (e.g. design complexity, defective materials, overlooked site condition, overemphasis on first cost, poor site practices and supervision)
- Human resources (e.g. lack of training and skills, lack of motivation and care, ignorance and lack of knowledge)

These human defect elements in new and modified projects along with existing deteriorated building defects will definitely increase with time, thus requiring continual improvement in building maintenance strategies. Therefore, in order to minimise the maintenance of human defects, a continuous improvement approach has to be integrated into the maintenance system.

2.5.4 The Need of SBM

Mostafa et al. (2015) described any maintenance service executed in maintenance environment as an intangible product. The customer who receives this service is known as an asset which, in this case, could be part of a sustainable building structure. According to Mohd-Noor et al. (2011), building maintenance is defined as keeping and restoring any defective part within a building to its original condition, maintaining the performance of the building services and surroundings to the required standards, and sustaining the value of the building. Their work study was focused on developing a framework that helps in allocating an annual building maintenance budget based on the guidance of the Queensland Government Departments of Maintenance Management Framework (QGMMF). The new approach has been driven by three main contributing factors: nonstandard work execution, misuse of financial management, and lack of planning and control.

Basically, building maintenance management starts with planning and moves to directing and organising, which is followed by controlling the maintenance activities in order to maximise the return on investment (Zawawi et al., 2011). Fong and Wong (2009) classified general building maintenance defects into building structure defects (e.g. roof, floor), equipment defects (e.g. furniture, machines), and service defects (e.g. electrical, mechanical).

Silva and Falorca (2009) proposed a model to be used in the planning, inspection, and maintenance of buildings. Their aim was to let the process identify and characterise all building elements. However, they focused only on representing civil structure components (e.g. foundations, walls, roof, doors, and windows) as part of assessing these particular elements against cracks, deterioration, and surface defects.

Zulkarnain et al. (2011) studied the critical success factors of building maintenance management from the perspective of internal processes, customers, finances, learning, and growth. Zawawi et al. (2011) investigated the maintenance management practices of Malaysian local authority organisations by focusing on maintenance policies and quality standards, resulting in development of a conceptual framework that enhances a proper implementation of CSF in building maintenance management. Both of these studies have referred to service quality as the main critical success factor in building maintenance management.

In order to ensure cost reduction in building maintenance management, Cavalcante et al. (2012) proposed an inspection model embedded with a multi-criteria approach to support decision makers based on time delay. Grussing and Liu (2013) developed a model framework that aims to identify and select multi-year building maintenance, repair, and renovation activities. They employed a genetic algorithm methodology to optimise maintenance activity selection considering the related capability, work performance, and life cycle cost.

A multi-criteria model was developed by Costa et al. (2012) to audit a predictive maintenance programme and hence measure the maintenance performance and its added value. The model was implemented in the general hospital of Ciudad Real (GHCR) in Spain and was accomplished with a hierarchical approach and weightage criteria along with value scales obtained from staff judgments through an internal questionnaire. Wang et al. (2013) applied energy benchmarking tools to evaluate overall office building energy performance, seeking opportunities to reach a cost-effective optimisation level. Approximately 10% energy savings was achieved after implementing cost-effective measures (e.g. sensor failures, and equipment degradation).

According to Suffian (2013), civil and structural elements (e.g. soil settlement, cracks, and waterproofing) are given less attention in building maintenance than electrical and mechanical systems. He explored some cases from the Social Security Organisation in which these defects might occur and how to tackle them. Unfortunately, he did not provide a sufficient review of workmanship training and education, in which they compose the backbone of knowledge improvement in any organisation.

A building maintenance and renovation model has been created to address problems of maintenance faced by facility management (Macek and Dobiáš, 2014). Even though this model ignores quality aspects, it is suitable for use by non-specialist users, with a provision that allows engineers to add more experience knowledge through the input interface of the application.

Hon et al. (2014) determined the correlation between safety climate and safety performance of repair, maintenance, minor alteration, and addition (RMAA) works. Two equally sized sample questionnaires were taken from building service contractors to test and validate the investigation model developed by the researchers. The results show a negative relationship between self-incidence and RMAA safety climate. On the other hand, a significant positive relationship was found among RMAA safety climate, participation and compliance. This result will support the criticality of ensuring health and safety in SBM.

Dukić et al. (2013) studied the cost consequences of not performing preventive maintenance in residential buildings managed by the Tenants' Council. They discovered that 46% of the annual total maintenance cost is wasted on frequent unexpected interventions and for the organisation of the Tenants' Council. On the other hand, the Tenants' Council focuses only on regular and variable maintenance activities without considering preventive maintenance; hence, this is evidence for the importance of management in reducing maintenance defects.

According to Chiu and Lin (2014), life cycle maintenance strategies will be applied when the service life in terms of safety or serviceability of reinforced concrete buildings does not meet the standard level. They derived the building owner decision tool of maintenance strategies using a fuzzy logic (a type of artificial intelligence technique) rule set based on deterioration type and related repair technology.

On the topic of SBM, Alnaser (2008) outlined some advantages of Sustainable Building transformation in hot countries: more energy-efficient performance, fewer emissions, less absenteeism, higher air quality, and longer lifecycle. According to Pulselli et al. (2007), Sustainable Buildings ensure resistance to physical degradation and hence maintain the main standard requirements in dynamic systems. On the other hand, Yahya and Ibrahim (2011) insist that health and safety play the most important role in forming SBM.

According to Kaufman and Balsley (2009), maintenance staff must be trained to handle Sustainable Buildings. This will ensure the benefits of reduced long-term energy costs, efficient use of resources, and healthier employees. They further provided brief technical guidelines on how to maintain Sustainable Buildings.

BOMA 360 Certification was developed in 2009 with the aim of assessing any type of commercial building against reliability of operation and maintenance, including sustainability, risk assessment, safety issues, energy, and training. As a prerequisite, the organisation must have a standard operation manual and active preventive maintenance program in addition to a valid benchmark with a certified energy company (Penny, 2012). Despite the BOMA approach in building performance assessment, their evaluation sheet does not assign high weightage to maintenance. In addition, there is no reference to quality assessment in conjunction with maintenance.

Ajukumar and Gandhi (2013) have described how green maintenance has provided a means of making maintenance more environmentally friendly by getting rid of all associated wastes. They have emphasised that designers must consider the green aspects and design for eco-friendly maintenance. They also have classified the green maintenance requirements into three main categories: environmental compatibility, energy efficiency and human health and safety risks. These have been integrated with a prioritisation technique to evaluate their importance during maintenance operation.

Seinre et al. (2014) developed a building sustainability assessment model that drives existing performance indicators to be benchmarked with the BREEAM and LEED standard requirements. The findings show that current energy and climate regulations (in Estonian standards) provide high scores for selected schemes (i.e. energy monitoring and system efficiencies). However, their model did not highlight the effect of maintenance as an aspect of performance indicators.

Chiang et al. (2015) have demonstrated an approach that can determine combinations of maintenance materials used while optimising life cycle cost (economic perspective), labour requirement (social perspective), and carbon emission (environmental perspective). However, one constraint at a time has to be chosen within acceptable levels while optimising the other two variables.

To summarise, it can be seen that previous studies in building maintenance have given some critical initiatives to issues such as life cycle cost and lack of building maintenance technical expertise. On the other hand, some other studies are beginning to deeply research the area of SBM. This can be supported by the clear evidence of a high rate in users' perceptions of sustainable building (Baird, 2015), the criticality of activating operation and maintenance manuals in low-carbon/sustainable buildings (Frank et al., 2015), and the guide to green maintenance and operation (Kaufman and Balsley, 2009).

2.6 SBM Taxonomy

From the experience of the researcher and close investigation of maintenance practices for sustainable buildings, it is found that sustainable maintenance taxonomy and strategies are not independent of the conventional maintenance processes and practices. However, it has been shown that there is a need for selecting different maintenance strategies according to sustainability pillars and their weightage criteria (Nezami and Yildirim, 2013).

Motawa and Almarshad (2013) investigated some general building taxonomy schemes in construction and building maintenance projects that aim to facilitate knowledge sharing across an organisation. In construction, these schemes are the construction index, RIBA (Royal Institute of British Architects) Uniclass (Unified Classification for the Construction Industry), and the Construction Specifications Institute (CSI). For building maintenance taxonomy, Ali et al. (2004) categorised knowledge of reactive maintenance into three classes: building maintenance, services, and equipment maintenance. However, Motawa and Almarshad (2013) designed their BM taxonomy based on existing BM contracts in the public sector. This scheme has been verified by professionals to suit the specified work environment.

This research will extend the use of this public BM taxonomy with a provision of verification and refinement in later stages. It will be presented as the main SBM taxonomy structure that will be embedded in the KB Lean6-SBM System. The schematic diagram shown in Figure 2.5 illustrates the building maintenance taxonomy. Therefore, the building maintenance management concern will target all administrative and technical actions required to ensure sustainable utility and value of a building. There are three categories in BM taxonomy (Motawa and Almarshad, 2013): administrative which contains maintenance process and staff index, technical which refers to the technical work package, and legal which serves contract conditions, bidding law, health, and safety.

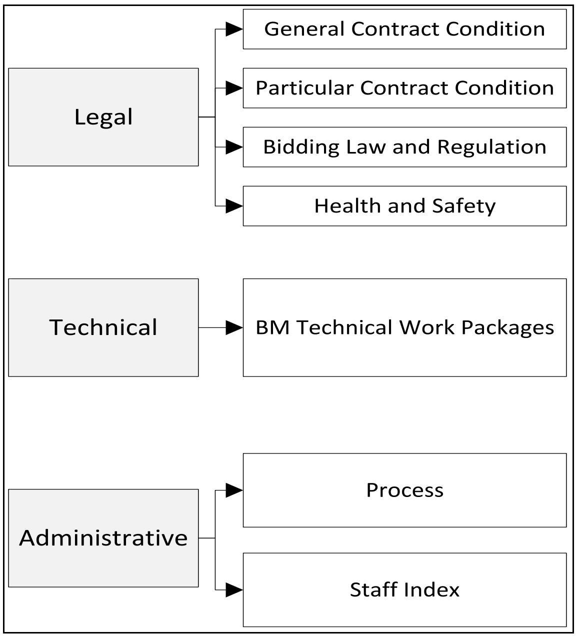


Figure 2. 5 BM taxonomy, modified from Motawa and Almarshad (2013)

2.7 SBM and Quality

Today, lifestyles and schedules are totally dependent upon performance satisfaction of products or services. Feigenbaum (2005) asserted that the word quality does not mean “the best” in any abstract sense. In other words, it is a determination to be made by the customer rather than engineers or marketing management. Therefore, there is a continuous need for adopting quality control systems to meet customer requirements.

As has been noted by Sui-Pheng and Wee (2001), there are five schools of thought for quality within the industry: conformance to specifications, fitness for purpose, fitness for purpose and conformance to specifications, system approach (socio-technical rationality, and technical rationality). They have studied the effect of implementing ISO9000 in a Singaporean construction company that has been certified in this regard. They concluded that despite the visible improvement triggered from the applied process, there was no study within the company to measure the improvements against such implementation; this is an essential step prior to claiming that a quality management system (QMS) has been successfully implemented.

Kwon et al. (2011) investigated the relationship between building maintenance management services and occupant satisfaction through two surveys of office buildings in Seoul, Korea. From the first survey, the results show up to a 60% correlation between maintenance services provided and level of maintenance management. In the second survey, two cases were selected for analysis, and the results show that occupants in both cases reported an equal level of satisfaction. In addition, occupant satisfaction is increased when they are actively used in the help desk support system.

Wm Chan et al. (2014) conducted a study to analyse building decay in Hong Kong and the results of implementing a mandatory building inspection scheme (MBIS) by the government. Most of the discovered defects were due to poor upkeep of building facilities such as fire system provisions, structural deterioration, and defective drainage and plumbing.

Generally, despite the strong correlation between building maintenance and quality aspects, few studies have been performed to accomplish a solid integration of well-known quality concepts (e.g. TQM, Lean, Six Sigma) in the SBM environment. Therefore, for this research, Chapter 3 will elaborate the importance of integrating Lean Six Sigma in the SBM context.

2.8 Summary

This chapter has provided some basic concepts on maintenance business excellence, and maintenance strategies with focusing on PM. This includes an overview to OM, TBM, CBM, and PdM. Then, the chapter presents a view to the most common used maintenance KPIs, which were categorised into leading and lagging indicators. Afterwards, a deep review in SBM was given, started with exploring basic elements of building construction and sustainable buildings, followed by giving an example from a recent statistical overview of maintenance demand and a historical evidence for the need of SBM. It has been declared the use of a conventional BM taxonomy as the key structure of the research SBM context. This contains legal, technical, and administrative perspectives.

A detailed review of previous studies has been undertaken in SBM and cases in which it has been integrated with quality concepts. The importance of quality in maintenance organisations has been highlighted as the core issue behind successful implementation of building maintenance strategies. Moreover, some examples of influential studies for implementing quality management systems and building inspection schemes in a building maintenance environment were provided. Despite the lack of studies in SBM, there is no doubt that global construction is moving towards sustainability, and hence much more concern must be introduced to the current practice of conventional building maintenance.

This chapter has reviewed in detail many concepts, strategies, and standards for achieving sustainable buildings. This detailed review has been very important not only for understanding purposes but also as a foundation for creating the KB which will be used in developing the knowledge rules in Chapter 5 onwards.

CHAPTER 3

Literature Review of Lean Six Sigma

3.1 Introduction

It had been shown from industrial practice and current investigation in literature review (George et al., 2003; Dhillon, 2006; Dukić et al., 2013; Milana et al., 2014) the large amount of waste (30–80%) that can be determined in maintenance environment. This chapter will highlight the importance of integrating Lean Six Sigma into the SBM context, as described in the previous chapter. The chapter begins by navigating through the historical background of some quality approaches followed by exploring the concept of total quality management (TQM) using the Oakland model as the basis of the research towards LSS implementation. It will then describe the basic elements of Lean and Six Sigma, and highlight their essential tools and techniques that will be incorporated to form the LSS. The chapter will be concluded with a critical analysis of previous studies conducted in the field of Lean and Six Sigma with the evidence support behind playing the major role in this research.

3.2 Quality Evolution

According to Joseph and Joseph (2010), quality refers to fitness for purpose, whether it be a product or service. They emphasise that customer satisfaction must be achieved with few defects and high efficiency in order to achieve high business performance. However, many manufacturers describe quality as the achievement of product/service specification requirements at the final test, which indicates a reduced focus on customer needs (e.g. packing, storing, and maintaining). On the other hand, Feigenbaum (2005) insists that customers' demands lead to sharply increased quality requirements (exceed expectations), which will force current quality practices and techniques to be outmoded in the long run.

According to Goetsch and Davis (2014), quality can be applied to people, processes, products, services, and environments. Therefore, total quality must be achieved through continuous improvement in all of these segments in order for an organisation to compete in the marketplace. To serve those segments, it is commonly agreed that quality has entered a continuous evolution, starting with operator-based auditing and ending with a quality performance measurement of zero defects. The pictorial graph represented in Figure 3.1 shows the milestone inventions of quality concepts. Török (2012) classified the evolution of these concepts into five stages: the foundation (1920s—1940s), the embellishment (1950s—1970s), the breakthrough (1980s), the perfect storm (1990s), and gathering the strength (the new century where LSS begins to spread). It has been emphasised in many studies that new quality approaches do not lead to the neglect of others, because they can be integrated into some industrial applications to achieve maximum added value (Talib and Rahman, 2011; Saleem et al., 2012).

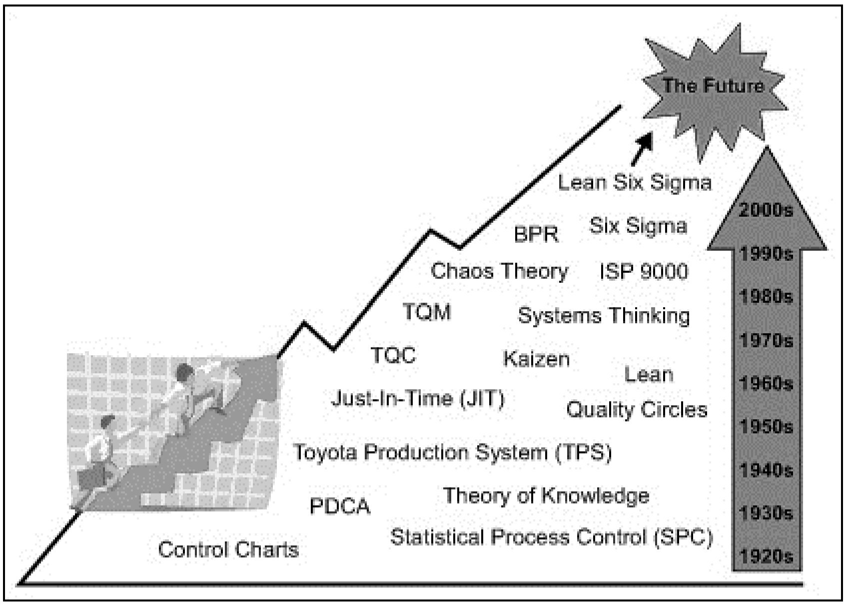


Figure 3. 1 Milestone inventions of quality concepts, adopted from Török (2012)

3.3 Total Quality Management (TQM)

Feigenbaum developed the concept of total quality control, which was later known as the Total Quality Management (TQM) philosophy. He defines product and service quality as the total composite characteristics in engineering, manufacturing, maintenance, and marketing that enable the product and service to meet the customer expectations (Feigenbaum, 2005). He clarifies that the word *quality* in the phrase *quality control* does not refer to the “best” in any abstract sense. In fact, it means the best from the angle of customer satisfaction, whether the product is tangible (e.g. a car, a mobile phone) or intangible (e.g. hospital care, restaurant service).

In fact, the TQM philosophy was developed later by Edward Deming, the American guru who started building his quality concept in Japan after the World War II. The definition of TQM according to the American Federal Authority is *"a total organisational approach for meeting customer needs and expectations that involves all managers and employees in using quantitative methods to improve continuously the organisation's processes, products and services"* (Saleem et al., 2012: 35).

Crosby has claimed that the price of non-conformance with quality standards is 30% of an organisation's revenue. He has led the contribution to the zero defect approach as part of the globally known fourteen steps of quality improvement program, which in fact enhances and in some cases contradicts what was driven by Deming and Juran (Crosby, 1980).

According to Saleem et al. (2012), TQM is classified into the soft part, which deals with human involvement and commitment, and the hard part, which is the representation of tools and techniques used to develop quality improvement. Rahman and Bullock (2005) studied the relationship between soft and hard TQM in the context of performance measurements. They proved the significant and direct effect of applying hard TQM elements to an organisation's performance. However, they found that the successful utilisation of soft TQM must be through implementation of the hard elements.

Talib and Rahman (2011) used the Pareto analysis technique to identify the critical success factors of implementing TQM in service industries. Twenty-one "vital few" factors are identified (e.g. top management commitment, training in operations and statistical skills, employee and customer satisfaction). However, these factors need further practical verification in the service industry, which might help in developing a quality integrated system in SBM context.

Therefore, quality is a dynamic philosophy that must be integrated with processes, products, services, people, and environments in order to obtain superior value as a result of achieving customer satisfaction. In the next section, some total quality models will be discussed as a gateway to derive the research quality parameters.

3.4 Models of TQM

The Malcolm Baldrige National Quality Award (MBNQA) and European Foundation for Quality Management (EFQM) are two examples of famous quality excellence award models used by many organisations around the world as TQM approach frameworks (Al-Tabbaa et al., 2013). María and Godwall (2012) performed a multidimensional analysis of 39 IQA&EQMs (International Quality Awards and Excellence Quality Models), which were randomly selected from the seven world continents. Their findings revealed that MBNQA and EFQM are the most important models that can serve as a guide towards TQM. However, this research will focus on an extended excellence revised TQM framework developed by Oakland (2014) from his famous TQM model, which includes teams, tools, and systems as the mainstays driven by the organisation process and the soft elements. These will be discussed based on the framework illustrated in Figure 3.2.

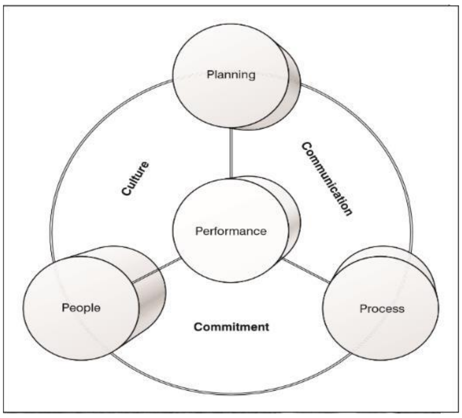


Figure 3. 2 Oakland TQM framework, adopted from Oakland (2014)

According to Oakland (2014), TQM can be integrated into any organisation through 4Ps: Planning, People, Processes, and Performance. These stages comprise hard TQM, whereas the soft factors that facilitate this integration consist of 3Cs: Commitment, Culture, and Communication.

3.4.1 Oakland Hard Elements

Rahman and Bullock (2005) proved that the strongest relationship between soft TQM and organisation performance represents the pivotal part within the hard elements.

3.4.1.1 Planning

TQM must be integrated into strategy, policy, and organisational goal setting. It must ensure the establishment of the organisation's resources and business relationships, maintain roles and responsibilities, and design standards and specifications. All together, these formulate the planning element within the model (Oakland, 2014).

3.4.1.2 Performance

In the performance stage, and per Oakland (2014), the critical area of performance measurement must be identified, which is called "SBM" in this research. The areas that must be modified based on the current level of performance will be tackled through the KB Lean6-SBM System. The system will be embedded by GAP analysis for benchmarking and AHP for prioritisation.

3.4.1.3 People

The enabler of the people stage is the key to activate the TQM soft elements. Oakland (2014) explained that organisational leadership is responsible to build teams, secure commitment from top management, ensure cross-functional communication between departments, and effect culture change. In addition to that, he insists on ensuring training in leadership skills and problem solving. From previous literature (Laureani and Antony, 2011; Albliwi et al., 2014), it is believed that most quality system implementation failures are due to unawareness of effective change management strategies. Some quality approaches such as Six Sigma do have built-in change management tools. However, these tools have to be revised to suit cultural change.

3.4.1.4 Process

The process element has the target of continuous improvement. This might be achieved by re-engineering the process, identifying process variables, and eliminating the non-value adding steps from the process. There are many tools and techniques that can play major roles in this area. However, according to the Oakland model, these must work in association to enhance the organisation's relationships with customers and suppliers. As a conceptual approach of this research, the concept of LSS will be applied. The Lean and Six Sigma attributes will be carefully selected to suit the research area based on an extensive literature review on SBM, Lean, Six Sigma, and LSS in addition to the researcher's experience.

3.4.2 Oakland's Soft Elements

As mentioned previously, people are the key element of activating Oakland's soft elements. Therefore, organisational performance cannot be achieved without strengthening the interrelationships among all elements, which will be correlated by the three Cs (Communication, Commitment, and Culture) working together. Singh and Mohanty (2015) conducted a survey to explore the role of culture in the relationship between organisational commitment and communication satisfaction. The findings indicate a positive relationship that is moderated by employees' culture values.

3.4.2.1 Communication

Zeffane et al. (2011) stated that communication is formal and informal sharing of meaningful and on time information. Oakland (2014) drew a systematic process of communication to be applied. He developed a communication process based on the Deming cycle (plan, do, check, and act/improve). In fact, it is necessary to design a communication plan for all phases within a project. This should include project goals, project tasks, project scope, and change management strategies (Hanafizadeh and Ravasan, 2011).

3.4.2.2 Commitment

According to Zeffane et al. (2011), it has been proved that employees' organisational commitment plays a significant role in supervisors' communication. They pointed out that a manager's ability to listen and lead is an important part of enhancing subordinates' commitments. This could justify the lack of commitment awareness and, therefore, the failure of many projects. Fu et al. (2015) found that applying a high level of education, training, and motivation will reduce the gap between employees and the organisation by achieving their commitments that aim to attain continuous improvement and therefore quality excellence.

3.4.2.3 Culture

Culture plays a major role in implementing TQM at all levels of leading organisations. Chen et al. (2013) developed an organisational culture approach based on three levels: prime assumptions, values and beliefs, and artefacts. The assumptions made are: TQM benefits my career development, TQM benefits my organisation, and TQM benefits my society. With regard to the second level, and towards a TQM culture, everybody in the organisation must adopt, believe in, and support five main values: commitment, customer focus, employee focus, continuous improvement, and participation. The third level intends to measure the awareness of employees towards TQM and how well they are performing.

According to Fu et al. (2015), the main pillars of building a TQM culture in any organisation are leadership, participation, empowerment, and systematic control. They have examined the *organisational change* approach derived by Chen et al. (2013) in seven companies that have been counted as TQM potential practitioners. The findings demonstrate a positive correlation between business performance and the companies' TQM culture.

Overall, it has been proved from previous researches that there is a significant relationship among communication, commitment, and culture, which have crucial effects on organisations and therefore will be the backbone that feeds and energises the structure of implementing LSS. However, from the researcher's experience, it has been noticed that each element might reflect variation in the degree of work execution and knowledge transfer owing to factors such as psychology and sociality.

3.5 Lean Thinking

Dahlgaard-Park and Dahlgaard-Jens (2006) described that one of the most popular concepts in quality is eliminating muda (waste), and this was the main primary philosophy of the Lean concept. The Lean concept was originated in Japan after the Second World War, where a high investment of rebuilding the devastated facilities compel the Japanese manufacturers to look for better approach in utilising minimum resources (Bhamu and Singh Sangwan, 2014). In fact, it was developed initially by Taiichi Ohno for the Toyota Production System (TPS) in the early 1950s (Womack et al., 1990).

Lean is a philosophy that aims to reduce the wastes in manufacturing process and accelerates the flow of the process activities that add value to the final product (Womack and Jones, 2003). According to Alves et al. (2012), Lean thinking has five main principles: identifying a value for the product/service (from the customer view-point), mapping the value stream of the process, creating flow for the process (by eliminating queues or non-added value steps), promoting pull production (as a short response of the customer's demand), and pursuing the perfection of the processes (by fulfilling the exact customer requirement with fair price and minimum wastes). However, Smith and Hawkins (2004) stated that it is very difficult to optimise these principles in a maintenance organisation before optimising the basic foundation of the maintenance elements (e.g. planning, scheduling, documentation, work order system, CMMS).

The integration of Lean thinking in maintenance creates Lean Maintenance (LM). The LM goal is to provide products or services at lower costs in a high responsiveness to customers' demands. Thus, the main idea is to eliminate waste or non-value added steps from the maintenance activities. It focuses on efficiency and minimises cost while reducing lead time and inventories. By applying Lean in a maintenance environment, many tools and techniques can be introduced to eliminate waste (e.g. Total Productive Maintenance (TPM), Kaizen)).

Finigan and Humphries (2006) suggest six tools that fit into Lean maintenance activities. These are visual control, five S (5S), seven wastes, single-minute exchange of dies (SMED), Poka-yoke (mistake proofing), and TPM. Mostafa et al. (2015) have categorised Lean tools based on previous LM practices. These practices/bundles are Just in Time (JIT), TQM, TPM, and Human Resource Management (HRM) which have been illustrated in Figure 3.3.

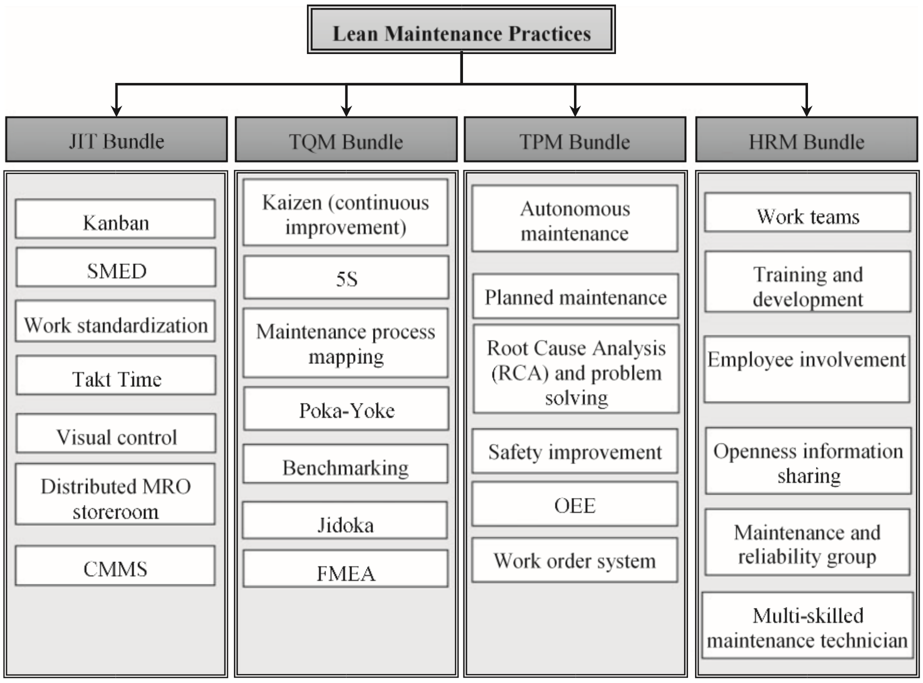


Figure 3. 3 Scheme for LM Practice Adopted From Mostafa et al. (2015)

According to Tendayi (2013), the highest performance of maintenance excellence criteria can be achieved by applying essential Lean tools such as, Visual Management, Kaizen, JIT, Kanban, 5S, Balanced Scorecard, and Poka-Yoke. Section 3.8 will discuss in details some of these LM tools.

3.6 Six Sigma

Schroeder et al. (2008: 540) defined Six Sigma as: *"An organized, parallel-meso structure to reduce variation in organisational processes by using improvement specialists, a structured method, and performance metrics with the aim of achieving strategic objectives"*. The parallel-meso structure refers basically to an external structure of program-leading qualifications. These are categorised into certifications' levels such as, Yellow Belt, Green Belt, Black Belt, Master Black Belt, and Project Champion/Executive (Dedhia, 2005; ASQ, no date). The highest qualification is the Project Champion, and the lowest is the Yellow Belt.

According to Schroeder et al. (2008) and Zhang (2009), Six Sigma was originally developed by Motorola in 1987 with an aggressive goal of 3.4 DPMO (Defects Per Million Opportunities) defects, in which the higher level of system defects are assigned with lower level of sigma. In other words, it can be said that the higher sigma level represents a higher process capability. In practice, it has been shown that the increase in process variation is equivalent to shift the mean of the process output up to ±1.5 standard deviations (Zhang, 2009; Mehrjerdi, 2011). This was justified statistically by Bothe (2002); in which he introduced the dynamic process capability as the factor affecting the mean variation.

Basically, the Six Sigma process capability is measured using two factors: Process Capability Ratio (C_p) which determines the process capability when the process mean is centred between the specification limits, and Process Capability Index (C_{pk}) which identifies the process capability when the process mean is not centred between the specification limits. In order to meet the specification limits, both C_p and C_{pk} must be > 1. Based on Kane (1986), these factors can be calculated using the following equations:

$$C_p = \frac{Upper\ Specification\ Limit - Lower\ Specification\ Limit}{6\sigma} \quad \text{, and}$$

$$C_{pk} = \text{Min}\ \left(\frac{mean - Lower\ Specification\ Limit}{3\sigma}\ ;\ \frac{Upper\ Specification\ Limit - mean}{3\sigma}\right)$$

Philip Crosby classified the measurement of the quality cost or Cost of Poor Quality (COPQ) in manufacturing industry into three types of costs: prevention, appriasal, and failure. These expenses are resulted from nonconformance (not meeting the specifications) or doying things wrong (Crosby, 1980), which are normaly utilsed to identify problem statements in Six Sigma projects. Salonen and Deleryd (2011) categorised the COPQ of PM into unnessary PM, and poorly performed PM. Table 3.1 shows the recommended world class levels (<15%) associated with the percentage of COPQ. It can be seen from the table that the average level in current industries is varying between 3 and 4 sigma with a defect rate (DPMO) of 67,000 and 6,200 respectively. However, adopting a continuous process improvement strategies leads to tolerate the target into zero defects.

Table 3. 1 Six Sigma Process Capability Adopted From Lucas (2002)

Sigma	Defects per million	Cost of poor quality	
6 sigma	3.4 defects per million	< 10% of sales	World-class
5 sigma	230 defects per million	10 to 15% of sales	
4 sigma	6,200 defects per million	15 to 20% of sales	Industry average
3 sigma	67,000 defects per million	20 to 30% of sales	
2 sigma	310,000 defects per million	30 to 40% of sales	Noncompetitive
1 sigma	700,000 defects per million		

Six Sigma is widely known by the model DMAIC (define, measure, analyse, improve, and control). According to Mast and Lokkerbol (2012), this method is developed in practice in the engineering industries. They emphasised that DMAIC is suitable to solve complex problem tasks if and only if it is required to expose all problem components (i.e. define, diagnose, and design solutions). On the other hand, they declared that it is not suitable for unstructured or subjective problems.

According to Lin et al. (2013), DMAIC methodology can be explained as: ***Define*** business value and results along with customer needs using critical to quality (CTQ) or voice of customer (VOC) methods, ***Measure*** and validate data that help set priorities and criteria, ***Analyse*** to determine root causes and well understand of the process and problem, ***Improve*** by developing solutions and refining goal statements, and finally ***Control*** and monitor the changes by developing a tracking process.

Chakraborty and Chuan (2012) conducted a survey in four service industries to assess the implementation of Six Sigma. They found that service organisations prefer to use soft tools rather than rigorous statistical tools, whereas the main success factor for the implementation is management and team support.

According to Antony (2006), the tools and techniques grid depicted in Table 3.2 illustrates a guideline for people who look for improvement in service organisations (e.g. building maintenance); it is to be utilised in different stages per the Six Sigma approach. However, some of these tools and techniques will not be covered in this research.

Table 3. 2 Recommended grid for SS tools and techniques to be used in service processes, adopted from Antony (2006)

Tools/Techniques	**Define**	**Measure**	**Analyse**	**Improve**	**Control**
Process mapping (2)	Y	N	N	N	N
Brainstorming (2)	Y	N	Y	Y	N
Root casue analysis (2)	N	N	Y	Y	N
Quality costing (1)	Y	Y	N	Y	N
Hypothesis testing (2)	N	N	Y	N	N
SPC (1)	N	N	N	N	Y
SIPOC (2)	Y	N	Y	N	N
SERVQUAL (2)	N	Y	N	Y	N
GANTT charts (2)	Y	Y	Y	Y	Y
Process capability analysis (1)	N	Y	N	Y	N
Regression þ correlation analysis (2)	N	N	Y	N	N
Benchmarking (1)	N	Y	N	N	N
Control charts (2)	N	N	N	N	Y
Pareto analysis (2)	N	N	Y	N	N
Cost-benefit analysis (2)	Y	N	N	N	N
Histograms (2)	N	Y	Y	N	N
Service FMECA (1)	N	Y	N	N	N
QFD (1)	Y	N	N	N	N
Affinity diagram (2)	N	N	Y	N	N
Project team charter (2)	Y	N	N	N	N
KANO model (2)	N	Y	N	N	N
Note: Y = applicable and N = not applicable; (1) = technique and (2) = tool					

3.7 Lean Six Sigma (LSS)

LSS is recognised as *"a business strategy and methodology that increases process performance resulting in enhanced customer satisfaction and improved bottom line results"* (Snee, 2010: 10). LSS is a quality philosophy that utilises the Lean management to speed up the process while applying Six Sigma. This is performed by eliminating the non-value adding elements/steps from the process. In fact, the whole process will be geared towards the minimum requirement of Six Sigma tools and techniques. Thus, Lean and Six Sigma are complementary.

In addition to eliminating waste, Lean improves speed and efficiency, whereas Six Sigma promotes effectiveness by removing variants from the process. According to Zhang et al. (2012), LSS utilises Lean and Six Sigma tools and techniques to form a powerful remedial action that can eliminate the problems behind implementing each one of these approaches. Officially, LSS uses belts in certification as in Six Sigma, which are Project Champion, Master Black Belt, Black Belt, and Green Belt, and Yellow Belt. The body of knowledge in these certifications evaluates the competencies in leadership, project management, change management, team working, LSS tools/techniques, and problem solving skills (Dedhia, 2005; BQF, 2017).

3.8 Tools and Techniques in LSS

Owing to the nature and complexity of this philosophy, which combines Lean and Six Sigma, there is a need to narrow their tools and techniques to suit the SBM environment. Based on literature and the researcher's experience in building maintenance, the following LSS tools and techniques have been selected, which will be verified by experts in a later stage of the KB Lean6-SBM System development.

3.8.1 Total Productive Maintenance (TPM)

Ahuja and Khamba (2008) stated that TPM is a technique that aims to maximise the efficiency of equipment through its lifetime by preventing unexpected quality defects, speed losses, and breakdown throughout the process. They classified and exposed 16 major losses in the manufacturing process for example, losses in overall equipment efficiency, equipment loading time, worker efficiency, and the use of production resources.

Swamidass (2002) highlighted the importance of integrating TQM, TPM, JIT, and employee involvement in the manufacturing environment because the typical maintenance cost varies in the range of 15-40% of the production cost. He emphasised that TPM is a critical success factor in improving equipment performance and increasing organisational capabilities.

McKone et al. (2001) tested the manufacturing performance against TPM as a result of a survey conducted in 179 manufacturing industries. They believe that TPM improves the manufacturing process by supporting JIT and TQM efforts.

With regards to perform a realistic LM, Mostafa et al. (2015) has emphasised that TPM practitioners have to ensure proper implementation of autonomous maintenance, planned maintenance, Root Cause Analysis (RCA), safety improvement, Overall Equipment Efficiency (OEE), and work order system.

3.8.2 Kaizen Events

Kaizen is a Japanese word that consists of two parts: *Kai* means "change", and *Zen* means "toward betterment". It refers to continuous improvement events as routine functions at a workplace within an organisation. Its mission is to create a learning organisation through some cross-functional events called "*kaizen* events”. These events aim to promote teamwork and participation from different departments in order to enhance organisational performance and provide a better way to perform a routine job (Saleem et al., 2012).

According to Singh and Singh (2009), *kaizen* as a concept was introduced by the Japanese scholar Masaaki Imai in 1986 to improve the quality at Toyota Motor Company in the face of increased competition worldwide. By implementing *kaizen*, the Japanese manufacturing sector achieved world-class excellence in efficiency, productivity, and competitiveness.

Saleem et al. (2012) explored the main elements of *kaizen* introduced by Imai, which are improved morale, self-discipline, teamwork, quality circles, elimination of waste (muda), housekeeping framework (5 S), improvement suggestions, and process standardisation. He has adopted Imai’s philosophy of continuous improvement tools and techniques under the umbrella of *kaizen* as shown in Figure 3.4.

Figure 3. 4 Tools and techniques under kaizen concept, adopted from Saleem et al. (2012)

Despite many arguments regarding where these tools and techniques belong: whether they should be under *kaizen*, TQM, or any future philosophy, the researcher believes that any tool or technique can be integrated or modified in one way or another to form a new conceptual approach. This means, for example, that JIT and quality circles can be referred to as part of TQM and *kaizen* at the same time.

3.8.3 Five S (5S)

5S is a Japanese workplace organisation tool which contains five words that start with the letter “S”: *seiri* (“sort” or “clear”), *seiton* (“set in order” or “configure”), *seiso* (“shine” or “clean and check”), *seiketsu* (“standardise” or “conformity”), and *shitsuke* (“sustain” or “custom and practice”). It is used widely with TPM to develop an integrated management system (Ahuja and Khamba, 2008; Rod et al., 2008). In 1993, the first comprehensive checklist of auditing 5S was developed by Samuel Ho with regard to the Malaysian government’s five-year quality plan (Karapetrovic and Ho, 2010). It was later updated by focusing on environmental attributes as described by Ho (2012).

According to Rod et al. (2008), the main objective of applying the concept of 5S is to optimise the degree of health and safety in a workplace environment, which will lead to reduced injuries and increased production. This must be maintained by building self-discipline through regular 5S audits that check employee involvement (Karapetrovic and Ho, 2010). Rod et al. (2008) studied the effect of 5S in the context of Japanese organisations. They noticed that Japanese organisations deal with 5S with regard to two elements first as a high organisation at the management Level that applies the philosophy “do it this way” in terms of overall and improved performance through participation, and second through the provision of organisational techniques that justify the “do” requirements. This approach was supported by Ho (2012) when he claimed that 5S has become the way of “doing” business via initiating effective quality processes based on prerequisites of high-level products and services.

Thus, it can be seen how important the utilisation of the 5S technique in the SBM context is; from the view of its contribution towards waste elimination, and health and safety at the maintenance work place.

3.8.4 Value Stream Mapping (VSM)

Haefner et al. (2014) described value stream mapping (VSM) as an effective way to redesign the engineering process. It consists of two parts: value stream analysis, which visualises the current process, and value stream design, in which waste sources are eliminated. Khalid et al. (2014) noted that any VSM project must involve an initial process called current state map (CSM) that outlines the existing work process; this will be modified to form the future state map (FSM), which will eliminate waste, improve the process, and add value.

Khalid et al. (2014) drew three benefits from using VSM: it provides a clear view of the value stream flow, it identifies wastes, and it prioritises future activities. They highlighted some problems that could act as barriers towards the successful broad implementation of VSM; these problems are time consuming owing to complexity and have no predictable outcome. However, these problems can be solved in maintenance by utilising the data obtained from maintenance management system (e.g. CMMS).

3.8.5 Statistical Process Control (SPC)

The term Statistical Process Control (SPC) is driven in the UK, whereas the same quality concept in the US is called Statistical Quality Control (SQC). According to Oakland (2008), and far from the popular meaning of SPC as a toolkit, it can be described as a strategy that aims to reduce variability. In fact, most quality problems are consequences of variations in products, materials, equipment, people’s attitudes, and everything for which the question must be asked continuously: “Could we do this job better?” The following tools provide a comprehensive method for any organisation to collect, analyse, and present most of its data:

- Control charts. Which variations do you need to control and how?
- Scatter diagrams. What are the relationships between factors?
- Brainstorming and cause-and-effect analysis. What are the causes of the problem?
- Graphs. Can the variations be represented in time scales?
- Pareto analysis. Implementing a 20/80 rule that aims to determine the most serious problems.
- Histograms. The illustrations of different variations.
- Process flowcharting. What is done?
- Check sheets/tally charts. How often is it done?

It is obvious that SPC tools can be widely used in maintenance activities as an effective approach to diagnose failures and defects (Duffuaa and Ben-Daya, 1995; Hanif and Agha, 2012; Madanhire and Mbohwa, 2016). For example, a histogram can be used to illustrate the distribution of breakdown in major equipment, and the distribution of tasks requested for rework. The cause and effect diagram can be used to identify root causes of excessive downtime, and ineffective scheduling. Pareto analysis can be utilised to determine spare parts that cause most delays, and crafts which cause majority of maintenance backlogs. Finally, the control charts can be used to monitor monthly maintenance backlog, and completion time of certain maintenance tasks.

3.8.6 Failure Mode and Effect Analysis (FMEA)

FMEA is a powerful technique that identifies failure modes and their effects. The main aim is to identify potential weaknesses in order to improve availability and reliability. Basically, a hierarchical decomposition is performed for a system or process into its main elements, which are then tested separately for cause-and-effect analysis (Schmittner et al., 2014).

Braaksma et al. (2013) examined the practical use of FMEA in PM through conducting multiple case studies. The study reveals that FMEA does not support the consistency in PM decision-making due to the fact that it is used as a one-off exercise, and the changes are usually made without referring to the original FMEA outcome. However, using FMEA in DMAIC cycle enforces the LSS project team to update its information throughout the process improvement.

3.8.7 Quality Function Deployment (QFD)

QFD technique was developed in Japan as a strategy approach to assure that new/existing products/services are built with a quality derived from customer requirements and market competition (Zairi and Youssef, 1995). They cited that the first use of QFD was carried out in 1972 by the Mitsubishi Heavy Industries Ltd. QFD seeks technical requirements at each stage during production or development (i.e. planning, design, production process, marketing strategies, and other engineering aspects) from the basic customer requirements (Mehrjerdi, 2010). Therefore, the Japanese has considered it as the best technique that spreads awareness of the need to focus on customer and encourages organisation’s commitment to achieve quality standards that match the customer expectations and the organisation business objectives (Zairi and Youssef, 1995).

With regards to maintenance, Tendayi and Fourie (2013) have utilised the QFD in combination with the AHP to evaluate the importance of the maintenance excellence criteria (at a railway maintenance organisation) and how they could be tackled through Lean Thinking tools. The study's results recommend the priorities (high importance to low importance) in implementing Lean methods starting with balanced scorecard, followed by visual management, 5S, Kaizen, standardisation, Hoshin, JIT, Kanban, and ending with Poka-Yoke. However, these priorities might not applicable to all types of maintenance activities.

All of the above tools and techniques have been successfully implemented in real-life applications. However, there is no clear evidence in the literature of integrating them in sustainable building maintenance through a KBS, which requires further verification and validation from related field experts. Nevertheless, from a theoretical perspective, sustainable or green maintenance is highly related to reducing lead-time (through eliminating wastes) and improving process variables. This enhances the need of integrating LSS in sustainable building context.

3.9 Previous Studies of LSS

LSS is a methodology of business improvement that aims to maximise shareholder value by focusing on improving customer satisfaction, speed, quality, and cost (Laureani and Antony, 2011; Franchetti, 2015). In fact, it is a mix of tools and principles from Lean and Six Sigma that complement each other. The adoption and successful implementation of LSS has been reported at some international organisations (e.g. Motorola and GE). Laureani and Antony (2011) stated that LSS entered an implementation channel in late 1999. However, there is no central certification authority, as with other quality principles (e.g. ISO 9000), and thus most of the practitioners are being assessed internally by their own organisations or external quality bodies (e.g. American Society for Quality (ASQ), International Quality Federation (IQF), and the British Quality Foundation (BQF)).

Some authors demonstrate the importance of applying LSS in green maintenance and related construction projects. For example, Al-Aomar (2012) developed a Lean Six Sigma construction framework based on five KPIs; quality, cost, speed, value, and waste. The framework was tested in 28 construction companies and the findings revealed the amount of wastes and process variables need to be tackled. Thomas et al. (2002) examined the impact of reducing workflow variability in construction projects' performance. They found that those variables were available in all projects, even in the stages which were classified as very good in progressing. In maintenance practise, Wang et al. (2012) proposed a rigid traditional Define, Measure, Analyse and Control (DMAIC) framework that articulated the implementation of LSS in equipment maintenance process. They have identified some causes that consequently drove their approach. For example, they found that quality management was not standardised, inspection personnel made decisions by guess rather than data analysis, and most work was based on individual ability rather than teamwork. In fact, for the customised DMAIC stages, the factors which caused major LSS project failures needed to be addressed carefully.

Zhang et al. (2012) conducted a review of 116 papers on LSS (published before 2012), and their findings revealed that most of the studies were focused on healthcare process improvement, manufacturing, financial services, military equipment services, and other general services. However, there was no evidence of implementing LSS in building maintenance.

Tenera and Pinto (2014) highlighted the essentiality of identifying critical-to-quality (CTQ) factors in early stages of implementing LSS, because it will reflect customer needs and opinions. Laureani and Antony (2011) explored the current LSS best practices in different industries; however, their study indicates that the high variation in the certification standard has caused difficulty in evaluating and measuring actual competencies and implementation success.

In his article (Antony, 2011) titled "Six Sigma vs Lean: some perspectives from leading academics and practitioners", Antony investigated some critical differences between the two principles by interviewing well-known international academic and business excellence practitioners. It is obvious that the major difference is that Lean focuses on waste elimination, including all non-value adding activities, whereas Six Sigma is used to improve organisational capability and process performance. They suggest that companies should start by applying a basic Lean approach such as the 5S housekeeping practice or current state map because they are easy to implement and require less investment. The final step will be the implementation of Six Sigma tools and techniques to solve chronic problems. Conversely, George et al. (2003) insisted that Lean and Six Sigma should be implemented together as a one interlinked concept.

Arnheiter and Maleyeff (2005) identified three different pillars gained with regard to each concept (i.e. Six Sigma and Lean management). With regard to Lean management, the value-added contents will be maximised in all operations, seeking global optimisation rather than local optimisation, and finally, it will incorporate the decision-making process based on customer satisfaction. On the other hand, pillars gained by a LSS organisation with regard to Six Sigma stressing a data-driven approach for decision-making, minimising variations by promoting and applying consistent methodologies and a well-structured training and education approach.

A survey was carried out by Aberdeen Group (2006) and targeted challenges faced by 400 companies that were practicing LSS, in addition to their response plan. The results (Table 3.3) show that the culture change is the most critical part (68%) followed by the data collection process (44%). The companies have attempted to resolve these issues by training and introducing gradual change. The least challenge was found in spending excessive time for data cleansing (19%), which was resolved in some companies by creating automated data collection methods to avoid further data errors (e.g. entry mistakes, duplication).

Table 3. 3 Challenges and Responses in Implementing LSS, adopted from Group (2006)

Challenges	% Selected	Responses to Challenges	% Selected
1. Significant culture change required	68%	1. Train employees	68%
2. Data Collection challenges	44%	2. Introduce change gradually	49%
3. Resistance from knowledge workers and middle management	28%	3. Assign senior management champions accountable for quantifiable results	44%
4. Continued commitment from top management after initial stage	26%	4. Engage Outside consultants	33%
5. Sustained company-wide training and certification program	20%	5. Deploy IT solutions in support of quality initiatives	27%
6. Cost of training and certification programs	20%	6. Recruit qualified/certified individuals from outside the company	25%
7. Excessive time spent “scrubbing” data	19%	7. Implement automated data collection	19%

In their findings from a survey conducted in 101 manufacturing and service companies, Laureani and Antony (2011) identified some critical success factors that could affect LSS implementation. The majority of respondents highlighted the importance of “leadership styles”, “organisational culture”, “management commitment”, and “linking LSS to business strategy”. Although the participant population was relatively small, the results were still valid in opening some open gates for future research. This study has been enhanced by Albliwi et al. (2014), who designed a paper survey targeting previous studies (1995–2013) to investigate critical failure factors in Lean, Six Sigma, and LSS, revealed 34 factors that affected LSS implementation. These top factors were related to a lack of top management buy-in, lack of training, poor project selection, and lack of resources.

Goh (2012) mentioned some practical difficulties on methods of LSS implementation. In fact, he argues that common service systems are not applicable to be benchmarked according to the normal distribution as in Six Sigma (instead, a Poisson distribution might be used). Therefore, the LSS project cannot be implemented based on the Six Sigma level without checking the behaviour of background data. In addition to that, top management, culture change and training are the main obstacles that provide a very practical hindrance against successful implementation.

According to Al-Aomar (2012), there are seven types of waste in the production and construction environment: delays, defects, excessive people movement, excessive transport, excessive inventory, over-production, and over-processing. He developed a framework using LSS to reduce these wastes in construction projects. Karthi et al. (2011) integrated LSS with QMS standard ISO 9001:2008 under the Six Sigma DMAIC phases. They argue that organisations must adopt this type of integration in order to ensure future competitive advantages based on the continuous improvement approach.

Despite a lack of central authority for LSS certification, LSS has been internationally recognised as a powerful concept. However, there are still some arguments on how to proceed with a proper implementation strategy that the researcher believe it will lead to catastrophic investment failure. It is obvious from previous studies that critical failure factors are just rotating around the three Cs of Oakland’s soft elements described in Oakland (2014). These are: Communication, Commitment, and Culture; which together indicate the criticality of integrating the same in LSS.

In spite of the wide range of LSS successful implementations in manufacturing applications, there is no clear evidence in the literature of the integration of LSS in sustainable building maintenance through a KBS. Nevertheless, from a theoretical perspective, sustainable or green maintenance is highly related to eliminating waste and improving process variables. This enhances the need of integrating LSS in sustainable building context.

On the other hand, different surveys indicate that more than 90% of projects conducted in Lean, Six Sigma, and LSS initiatives (Laureani and Antony, 2011; Goh, 2012; Albliwi et al., 2014) show both resistance to change and management commitment as key barriers to successful project implementation. Despite the built-in change management awareness process in the DMAIC model, there is a need for a comprehensive plan to assess and analyse the readiness to change in order to tackle such obstacles. These are mostly related to the entire process and human factors in BM environment like cross-functional support and training.

Thus, this research will focus on facilitating the implementation of LSS in SBM context based on DMAIC cycle and a readiness for change approach, standard document (e-Careers-Limited, 2013), and practical observation.

3.10 Summary

This chapter describes the major quality concepts and provided an overview of quality evolution and adopting the Oakland model as an excellent TQM model to further explore the Lean Six Sigma concept and related tools and techniques. This has been driven by investigating the integration of the TQM hard elements known as the 4Ps: Planning, People, Processes, and Performance in addition to the soft elements that facilitate this integration and consist of 3Cs: Commitment, Culture, and Communication.

An overview of Lean Thinking and Six Sigma concepts was delivered with related implications in maintenance management. Furthermore, the chapter has highlighted some critical tools and techniques that could fit for maintenance management based on Finigan and Humphries (2006), Braaksma et al. (2013), and Mostafa et al. (2015) with respect to Lean, and Duffuaa and Ben-Daya (1995), Antony (2006), Hanif and Agha (2012), Tendayi and Fourie (2013), and Madanhire and Mbohwa (2016) with respect to Six Sigma.

It has been stated earlier that this research will focus on integrating Lean with Six Sigma aspects that suite the PM initiative in buildings’ maintenance environment. There are various LSS tools and techniques which can be used during the implementation in SBM, however, these need to be validated and refined in later stage.

According to the review of previous studies undertaken for LSS, some critical failure factors have been highlighted. It has been found that implementing LSS in the SBM context will encounter the same management obstacles unless it integrates a readiness for change framework prior to proceed with the DMAIC methodology.

This chapter has reviewed in detail many concepts, tools, and techniques that assist in implementing LSS in SBM context. This detailed review has been very important not only for understanding purposes but also as a foundation for creating the KB which will be used in developing the knowledge rules in Chapter 5 onwards.

CHAPTER 4

Literature Review of Artificial Intelligence Concepts and Methodologies

4.1 Introduction

From the 1980s–1990s, the hierarchy of data, information, and knowledge is used and known as the DIK framework. It was then expanded into the concept known as DIKW (data, information, knowledge, and wisdom), which was driven by Zeleny (1987), who described the analytical details of the framework (Jifa, 2013). In 1989, Ackoff added the understanding of relational patterns and principles to the DIKW framework.

According to Ackoff (1989), Nonaka and Takeuchi (1997), and Jifa (2013), researchers agreed to add the word *moral* to the DIKW framework, where they saw that wisdom must be directed towards good or bad actions, which would be distinguished by adding morality to the concept.

In 1990, Qian Xuesen initiated a new, grounded theory, “Theory of Meta-Synthetic Wisdom”. It integrates natural, social, engineering, art, and cultural science to obtain wisdom. This is done by collecting all relevant information, knowledge, experiences, and wisdom from past and modern times (Jifa, 2013).

This chapter will aim to define, analyse, and critique the elements of the DIKW framework, which will elicit a clear understanding of artificial intelligence concepts and methodologies in manufacturing considering that maintenance is part of this sector. Finally, the chapter will navigate through possible concepts and methodologies needed to incubate the research knowledge into a Knowledge Base System (KBS)/Expert System (ES).

4.2 DIKW Definition

In order to explore the DIKW framework mentioned above, the study must define the elements behind this hierarchy. In addition to recent studies, Zins (2007) study contains around 130 definitions for data, information, and knowledge, which have been documented from 44 scholars. However, according to Rowley (2007), wisdom is rarely defined compared to other elements. Besides this hierarchy, intelligence plays a major part in this game. However, it cannot be counted as a separate Level in the hierarchy, as it will be explained later.

4.2.1 Data

Data are facts or symbols that can be measured and stored but have no value. Aven (2013) stated that data are symbols that are taken from observations of events, objects, and their environments. According to Zins (2007), data are quantitative facts and statistics, which they can be counted, measured, and stored.

“Data are recorded symbols and signal readings, where symbols include words, numbers, diagrams, and images, which are the building blocks of communication. Signals include sensor and/or sensory readings of light, sound, smell, taste, and touch. Therefore, the main purpose of data is to record activities or situations, and attempt to capture the true picture or real event” (Liew, 2013: 49).

This definition matches other definitions proposed by Frické (2009), and Aven (2013). In modern organisations, many departments are using computer-based systems to record and store data in databases, Extensible Mark-up Language (XML), and spread sheets. Table 4.1 illustrates a type of data stored in a database where it can be seen that it has no value or is not understandable.

Table 4. 1 Data stored in spreadsheet

6052020										
			G							
A	R	C	D	V	Y	N	M	S		
								A-B	B-C	A-C
			RPM	%	PSI	PSI	PSI	KV	KV	KV
100	14.1	11.1	8961	100	31.9	31	186	10.9	10.9	10.9
200	13.9	11	8952	100	34.5	35	201.1	10.9	10.9	10.9
300	14.1	11.3	8910	100	31.9	32	187	10.9	10.9	10.9

4.2.2 Information

Information is data with meaning. Aven (2013) insisted that information is relevant processed data, where data has no value unless it is transformed into form. Hence, the difference between data and information is only functional, not structural (Aven, 2013). Information that is based on practice plays a major role in developing new hypotheses in the field of knowledge in action (Pronk, 2012). According to Liew (2013), information is a message that has relevant implications and meaning for actions and/or decisions.

However, the debate of interrelation is still valid since information science includes knowledge organisation and knowledge management (Zins, 2007). Therefore, it can be seen from Figure 4.1 that information comes from both historical processed data and current communications as an automated conceptual query that will lead to semi-automated integration between ontologies (Silberberg and Mitzel, 2005).

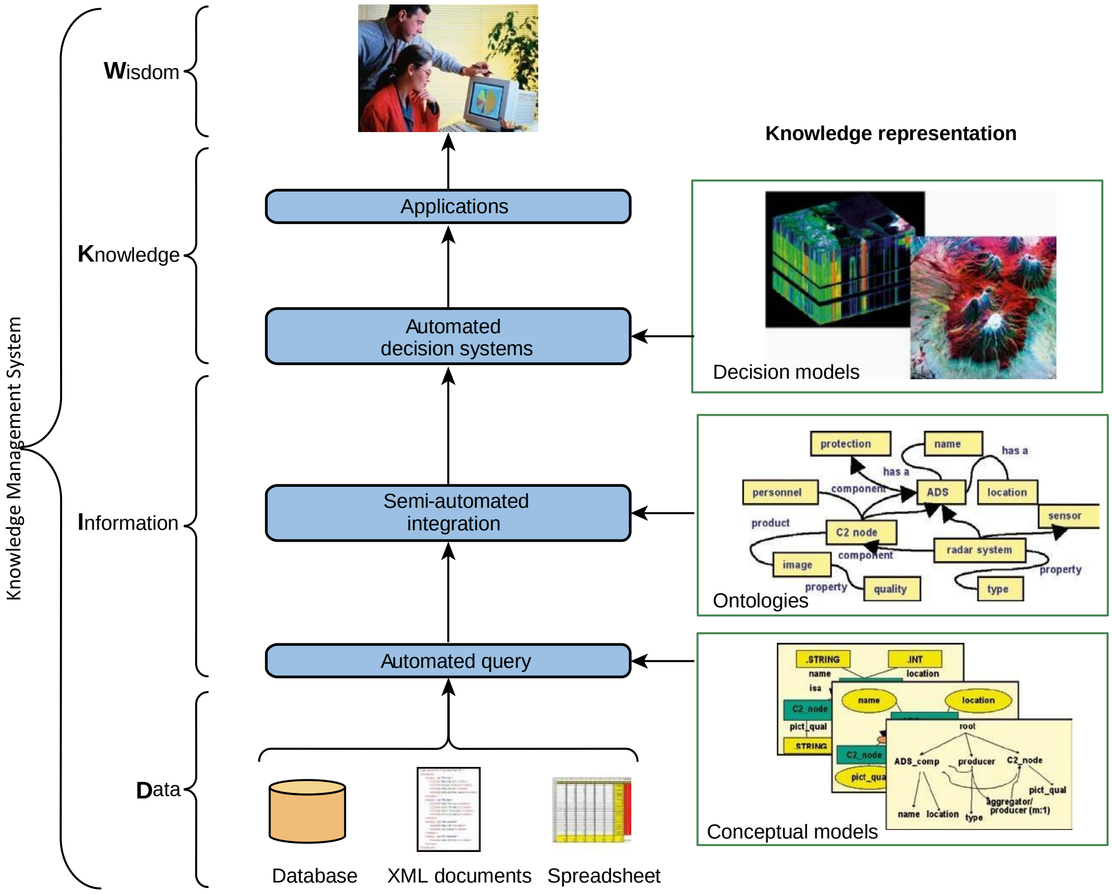
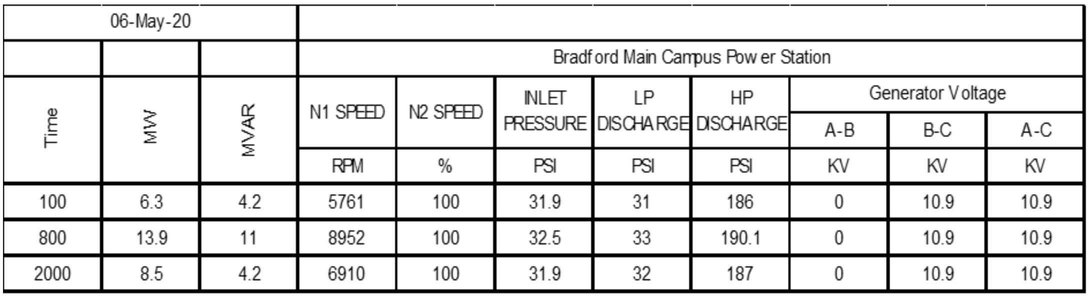


Figure 4. 1DIKW hierarchy using knowledge representation, modified from Silberberg and Mitzel (2005)

This can be clarified again from Table 4.1, where the data that has been recorded in the log sheet can be utilised if the parameter codes and their units of measurement are known. Therefore, knowing the definitions of the parameters, we lead to understand the data, as shown in Table 4.2, which obviously describes the power consumption in the Bradford main campus power station according to the load distribution control, as recorded on 06 May 2020.

Table 4. 2 Power generation log sheet



06-May-20										
			Bradford Main Campus Power Station							
Time	MW	MVAR	N1 SPEED	N2 SPEED	INLET PRESSURE	LP DISCHARGE	HP DISCHARGE	Generator Voltage		
								A-B	B-C	A-C
			RPM	%	PSI	PSI	PSI	KV	KV	KV
100	6.3	4.2	5761	100	31.9	31	186	0	10.9	10.9
800	13.9	11	8952	100	32.5	33	190.1	0	10.9	10.9
2000	8.5	4.2	6910	100	31.9	32	187	0	10.9	10.9

4.2.3 Knowledge

Knowledge is the information, experience, and ideas that are possessed by a person, a group of people, or an organisation. According to Negnevitsky (2011: 25), *“Knowledge is a theoretical or practical understanding of a subject or a domain”*. It is a “know-how” process or a familiarity that enables an individual to perform a task. Basically, it accumulates three main elements: facts, procedural rules, and heuristics (Awad, 1996). The know-how process is a continuous process that can be achieved in any organisation by several means. Knowledge is created in processes that have the dimensions of space and time (Hautala and Jauhiainen, 2014). To illustrate this, a newly recruited engineer must be given on-the-job training (OJT) before fully authorising the new engineer with actual job description responsibilities. In fact, the new recruit should be trained in various departments with related experts in all expertise aspects. In addition to theory and practice, knowledge contains tacit and explicit elements (Nonaka and Takeuchi, 1997; Ibert, 2007). Tacit knowledge is largely contextual and difficult to practically communicate, whereas the communication in explicit knowledge is easily codified as text (Hautala and Jauhiainen, 2014). According to Aven (2013), knowledge as know-how is used to generate instruction relevant to the information given.

In reference to Table 4.2, the following statements represent an explicit and tacit knowledge, respectively:

a. The maximum power consumption on 6th May 2020 for the Bradford main campus power station was registered at 0800 am with a value of 13.9 MW.

b. There is a defect in voltage gauge indicator (A-B).

Knowledge creation requires interaction and interpretation as key processes. The interaction process is a two-directional process in which human discussions and responses can challenge the thinking process more than intelligent machines and equipment (Berger and Luckmann, 1991).

Alternatively, the interpretation process is proving a simple link between information and knowledge; therefore, it transforms information into meaningful and valid knowledge (Davenport and Prusak, 1998). Practically, knowledge must be from a context and implemented into a context, whether social, physical, or psychological environments (Pronk, 2012). However, any tacit knowledge must be converted into explicit knowledge in order to be used in a KBS.

4.2.4 Wisdom

Wisdom is the ability to understand knowledge, create new knowledge, and apply this in the decision-making process. Sternberg (1986) described that wisdom is using experience for everyday difficult situations. It has different terminologies in Western and Eastern classifications, although all of them are linked into the concept of enlightening knowledge to others, understanding self-knowledge, creating new knowledge, and applying the same to concerns (Jifa, 2013).

Recent studies have discussed the concept of wisdom from two angles: culture and technology. It is obvious that wisdom is the main component in artificial and natural systems (Jaimini and Panchal, 2014). Since the research target is the creation of a KBS, the focus will be on wisdom technology. According to Jankowski and Skowron (2007: 95), wisdom can be formulated as follows:

“Wisdom = KSN +AJ +IP

Where *KSN, AJ, IP denote Knowledge Sources Network, Adaptive Judgement, and Interactive Processes, respectively”.*

Bellinger et al. (2004) insisted that wisdom is incorporating vision and design; therefore, it deals with the future rather than grasping the past and present. It is a process that requires a soul, which will never be tackled by machines. The present authors argue with this from the point that the future might be designed and predicted according to past and present measurements. Jifa (2013) stated that wisdom sources come whether by individual and collective wisdom, which is known as wisdom of the crowd or by machine wisdom, which is known as artificial intelligence (AI).

As an interesting example, when a certain item needs to be declared for major overhauling, although the manufacturer must put default recommendations in a manual (e.g. according to item running hours), the site engineer may delay or forward the declaration decision based on experience and the practice that has been learnt and understood. This might lead to a big savings or a severe loss in machine performance, in addition to other financial impacts.

4.3 DIKW Arguments

The hierarchy model of DIKW framework is used to contextualise data, information, knowledge, and wisdom as well as to identify the transformation process of an entity from a lower Level to a higher one, assuming that the data can create information, information can create knowledge, and knowledge can create wisdom (Rowley, 2006). However, she disagrees with many researchers regarding the consideration of DIKW as a wisdom hierarchy due to the pragmatic issue of illustrating wisdom as the main objective without the need to move from an implicit method of defining the hierarchy elements to an explicit approach. Zins (2007) attempted to formulate five different models to define data, information, and knowledge from internal and external phenomena perspectives by applying the critical delphi approach (an approach targeting a group of experts and aiming to attain consensus among them (Diamond et al., 2014)). In fact, the study would be more powerful if wisdom was added into the chain.

According to Davenport and Prusak (2000), the knowledge element is not easy to define, as it is a mix of contextual information and framed experience. It contains human complexity and intuition, which means that wisdom is counted within the knowledge Level. This concept was supported by Maier et al. (2009), who elaborated on the historical development of shifting from data to information and then to knowledge management. They have distinguished between two types, *knowledge as an object* (i.e. experience databases, and documented customised reports) and *knowledge elements* (i.e. definitions, concepts, processes, and rationale for actions).

On the other hand, Maxwell (2013) suggested that knowledge and wisdom are different in that there are two science empiricisms: standard that is related to *knowledge inquiry* and aim-oriented that is referred to as *wisdom inquiry*. The knowledge inquiry is justified and modified causing the emergence of the wisdom inquiry. Despite all arguments, the formulations of the DIKW hierarchy suggested by scholars demonstrates a common view, where the key elements are the same and arranged in a similar order (Rowley, 2006).

In fact, all the DIKW framework elements are valid; therefore, the wisdom Level cannot be eliminated, as it represents the decision-making Level. Nevertheless, the same will be part of the knowledge management business process. The nearest pattern that simulates modern thinking was delivered by Silberberg and Mitzel (2005) with the modification of adding the knowledge management system to act as the umbrella of all DIKW framework elements (see Figure 4.1).

4.4 Intelligence

Intelligence is the ability to understand and utilise knowledge for the best use of decision-making process. In fact, it is nearly close to the term wisdom, which differs by using extensive experience. Negnevitsky (2011: 438) defined intelligence as, *“The ability to learn and understand, to solve problems and to make decisions”.* In other words, it can be differentiated between knowledge and understanding as the difference between memorising and learning, which is required in each step. Therefore, understanding/learning/intelligence is not a separate Level in the hierarchy (Bellinger et al., 2004), which is, from the researcher point of view, passing the argument with the later study conducted by Liew (2013) and Jaimini and Panchal (2014).

4.5 Human Intelligence

Hampshire et al. (2012: 1233) described the human intelligence as the *“most parsimoniously conceived of as an emergent property of multiple specialized brain systems, each of which has its own capacity”*. Lohman (1989) has tried to elaborate on the question of how to derive a theory of intelligence from general thinking theories currently advanced in AI and cognitive psychology. According to Rasskin-Gutman (2009), the nature of intelligence have been tackled by three schools to generate related theories. The psychometric school, which measures intelligence through the intelligence quotient (IQ), the biological school, which aims to correlate intelligent activities with brain functions, and the school of cognitive psychology, which describes how to underlie intelligence by the mental process.

Many situations could explain human intelligence; for example, an expert instrumentation technician can diagnose and repair any instrument failures within a minimum time without the need of manual revision. Some auto mechanics can detect the defected part from the sound while in operation.

4.6 Artificial Intelligence

After the Second World War, Alan Turing (British mathematician and computer scientist) used his practical experience in developing coding systems and theoretical concepts of a universal computer to derive the key fundamental questions of AI (e.g. Is there thought without experience? Can machines think?) (Negnevitsky, 2011). Nevertheless, Turing did not provide evidence that answered these questions; instead, he developed a game that can assess such thinking, which was later called the imitation game by Turing (Turing, 1950; Negnevitsky, 2011).

The imitation game concept, which was invented and developed by Turing, is shown in Figure 4.2. The first phase illustrates three parties: the interrogator, a male, and a female. They are placed in different rooms and allowed to communicate through a remote terminal. The main objective of the interrogator is to differentiate between the male and the female by questioning them. The game rule is that the male should try to influence the interrogator that he is the female. In the next part of the game (Figure 4.2, second phase), the male is substituted by a programmed computer, which must attempt to deceive the interrogator as the male previously did. If the programmed computer can deceive the interrogator as much as the male did, then it can be said that this computer has passed the behaviour intelligence test.

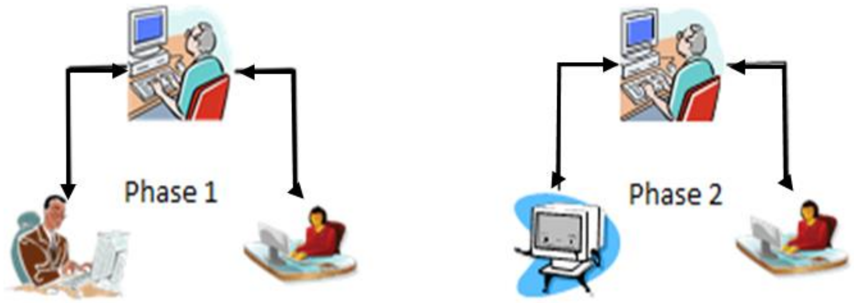


Figure 4. 2 Turing imitation game, adopted from Negnevitsky (2011)

Negnevitsky (2011), Oppy and Dowe (2011), and Hernández-Orallo et al. (2012) have justified the roles and distributions in more detail in the Turing tests with the possible instances (whether by observation or by interrogation).

Hernández-Orallo et al. (2012) pointed out that the most debateable feature of the Turing test is when validating machine intelligence, humans are a touchstone of the process; therefore, the human judge is the assessing strategy, which contains controversy. In addition to that, there is another feature, where the restriction channel of having a teletype conversation is still valid.

Artificial intelligence is the science of developing machines to do things that would require an intelligent contribution if done by a human being (Bolter, 1984). Programs that come under AI can distinguish between the knowledge given and inference engine rather than traditional scientific calculation programs. That is because of the explicit knowledge base from the inference engine, which provides an easy way to trace input data as well (Widman and Loparo, 1990).

The application of enterprise resource planning (ERP) can be used as an example of an AI tool, which integrates multi-discipline modules (i.e. maintenance, inventory, finance, procurement, etc.) in one or more programming languages. The built-in business intelligence tool plays a major role in generating customised scientific reports in no time.

4.7 Artificial Intelligence Concepts and Methodologies

Widman and Loparo (1990) defined systems that perform certain tasks as AI systems, where, if a human being performs it, the task would require intelligence. Another similar definition is stated by Negnevitsky (2011: 426) in his book*, "AI is the field of computer science concerned with developing machines that behave in a way that would be considered intelligent if observed in humans".*

Teti et al. (1997) classified AI into its functions, techniques, and suitable applications in the manufacturing sector, where it can be implemented (see Table 4.3). It is obvious that AI techniques are extensively used in different manufacturing sectors.

Table 4. 3 AI Functions and techniques in manufacturing, adopted from Teti et al. (1997)

Artificial Intelligence tools and techniques in Manufacturing environments		
AI functions	***AI techniques***	***Manufacturing Sector***
Learning	Genetic algorithms	Design
Knowledge	Neural networks	Planning
Reasoning	Fuzzy logic	Production
Goal-seeking	Neuro-Fuzzy	Scheduling Systems
Pattern recognition	Simulated Annealing	Assembly
Decision Making	Expert Systems	Monitoring
Advice	Knowledge Base	Control
Communication	Systems	Inspection
Control	Hybrid systems	***Maintenance***
Self-improvement	Multi Agents	***Quality Management***
Self-maintenance		
Self-organisation		

According to Madey et al. (1994), a hybrid intelligence system can be defined as a problem solving mechanism, which is formed by integrating more than one intelligence technique that could be illustrated at the base of the triangle shown in Figure 4.3. In spite of the logical systematic approach of the triangle concept driven by Madey et al. (1994), the question of stating AI as part of the techniques must be revised.

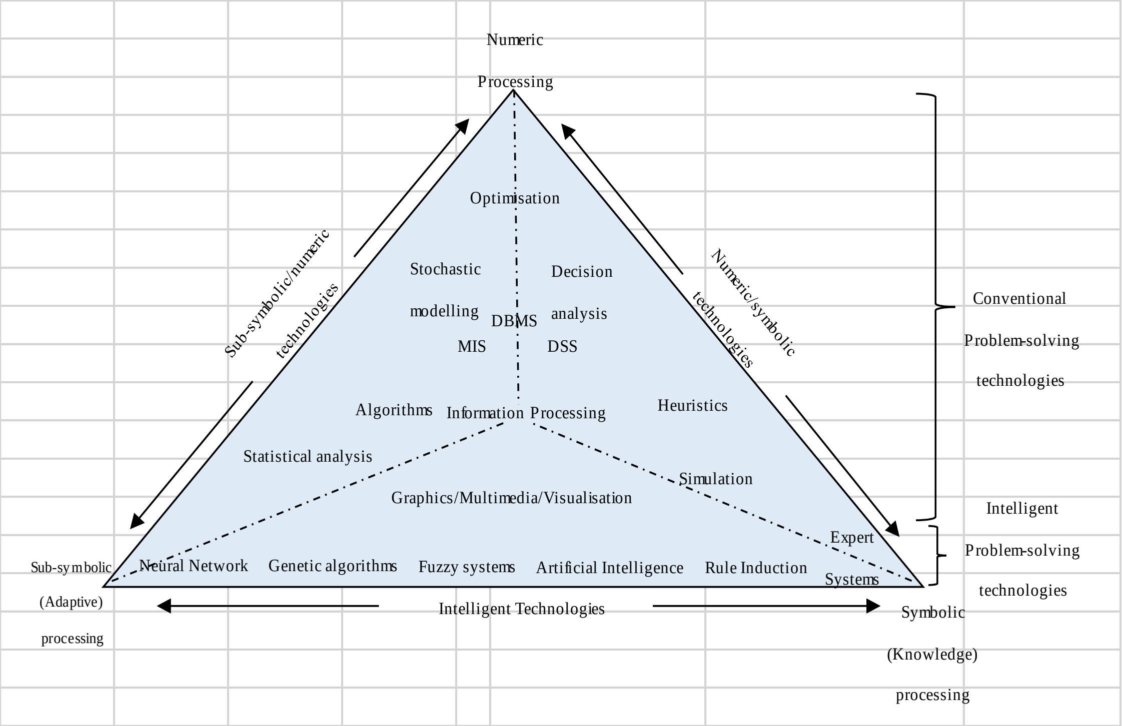


Figure 4. 3 Intelligent problem solving technique, adopted from Madey (1994)

The recent design approach is toward integration among different AI techniques, which is due to the ineffectiveness of distributed representations and a variety of complex data in the real world (Dagli, 1994). This chapter explores seven of these tools, which are case-based reasoning (CBR), genetic algorithms (GAs), artificial neural networks (ANNs), simulated annealing (SA), frame-based system (FBS), fuzzy logic (FL), and KBS/ES.

4.7.1 Case-based Reasoning (CBR)

Case-based reasoning is a paradigm that combines learning and problem solving as one of the most successful AI subfields applied in recent years (Castro et al., 2011). According to Fan et al. (2014) and Sampaio et al. (2014), the CBR can be defined as the process of solving new problems by learning from previous similar problems. The idea of CBR in AI was proposed by Roger Schank through his study of dynamic memory, followed later by some revisions and system development models (Aamodt and Plaza, 1994).

The famous CBR cycle has been driven by Aamodt and Plaza (1994), which is illustrated in Figure 4.4. Essentially, the process runs through four axial levels: retrieve, reuse, revise, and retain. It starts by applying a new case that has been triggered from a certain problem. The new case is used to retrieve a set of similar cases that have been solved in the past and recorded in the KBS. Then, the new case is combined with the old retrieved cases in order to solve the problem. After that, the revised solution is validated (e.g. in the real world or theoretically by experts or teachers) and repaired if it fails. In the retain stage, the solution that has been adopted must be updated in the system with the new modifications.

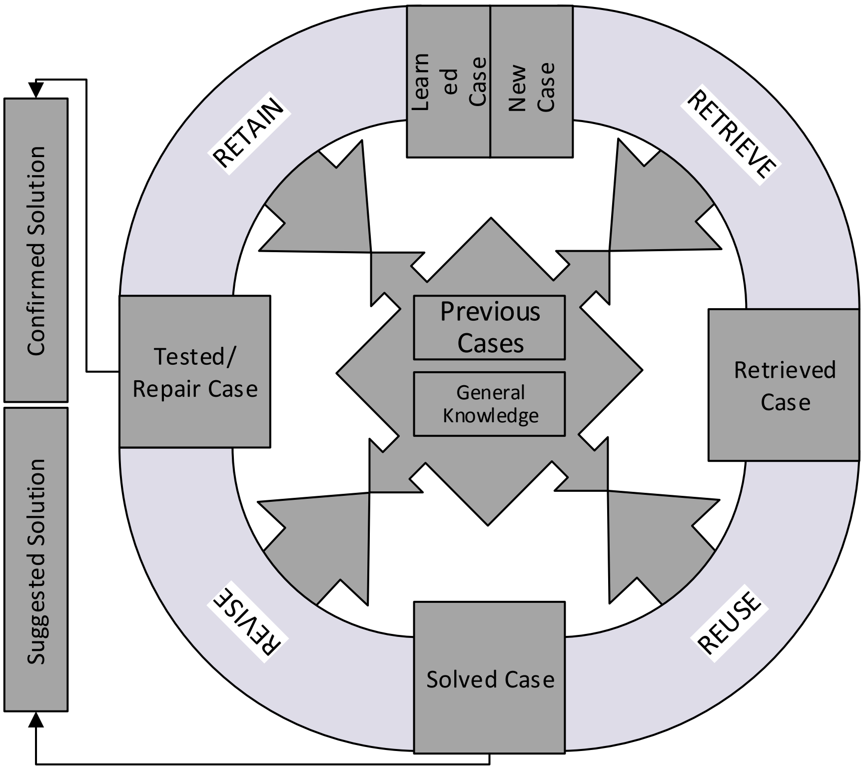


Figure 4. 4 The CBR Cycle, according to Aamodt and Plaza (1994)

An example of this model is to establish an electrical failure defect knowledge base – CBR system that aims to attain a remedial action for any unexpected defect in the powerhouse. The old cases must be categorised and recorded in the general knowledge database and retrieved by the type of defect. When a new case/problem occurs, it will be jointly benchmarked with old ones, and the most similar ones will be selected/retrieved. Next, the selected case will be reused and modified, if required. Finally, the system must be updated with the modified/repaired case.

4.7.2 Genetic Algorithm (GA)

According to Mitchell (1999), GAs were initiated and developed by Holland and his students and colleagues at the University of Michigan in the 1960s and 1970s. Goldberg and Holland (1988: 95) has defined the GA as, *"probabilistic search procedures designed to work on large spaces involving states that can be represented by strings. These methods are inherently parallel, using a distributed set of samples from the space (a population of strings) to generate a new set of samples".* In other words, GA generate possible solution (population) encoded as chromosomes and evaluating their fitness to create new population through GA operators such as crossover and mutation (Negnevitsky, 2011). Another definition has been stated by Munakata (2008) in which GAs are computer models based on biological evolution and genetics.

There are three main steps of GAs, which satisfy a common agreement between researchers Mitchell (1999), Deb (2001), Roy et al. (2008), Goodman (2010), and Negnevitsky (2011). They agree that GAs have the following operators:

a. Selection of solutions based on their fitness.
b. Crossover to generate new offspring.
c. Mutation of the new offspring.

The flowchart shown in Figure 4.5 represents the working principle of a GA drawn by Deb (2001) and Goodman (2010) which matches the more detailed functional flow process adopted by Negnevitsky (2011). The process begins when GA selects a random set of solutions and creates a population (i.e. binary strings by encoding the solutions as chromosomes). This generation is then evaluated towards having a suitable fitness; the evaluation means that calculations should meet the constraint violations and the objective function value. Thereafter, a termination condition must be checked (if applied), otherwise the process of creating a new generation will be carried out by the three main operators mentioned above (Deb, 2001).

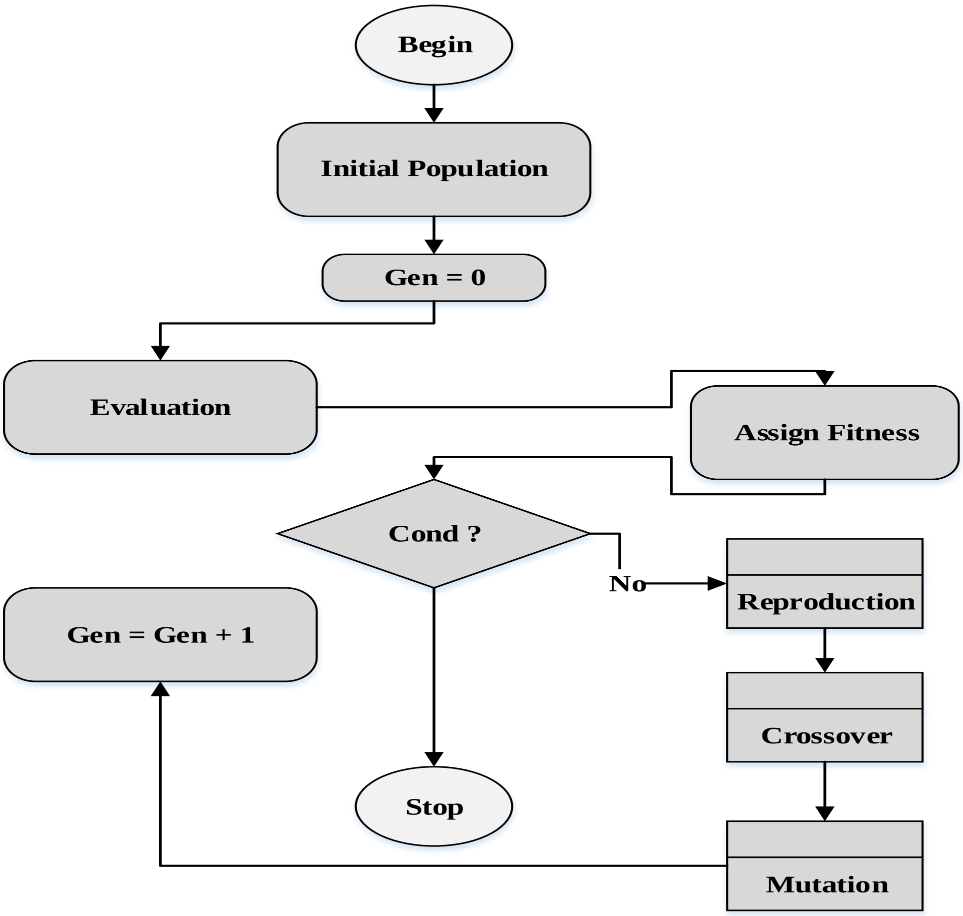


Figure 4. 5 The GA operational flowchart, adopted from Deb (2001)

The objective of reproduction is to identify good solutions and eliminate bad ones by creating a mating pool which is a method of separating individuals who create offspring from the current population (Langdon and Poli, 2002). The higher fitness solutions will tend to survive into the next generation based on the evolution concept of natural selection (Munakata, 2008).

After reproduction, the population is manipulated by crossover, which combines the characteristics of two parents from the population in order to produce a new generation (Roy et al., 2008). The last operational process is the mutation, which is done by randomly selecting a small portion of the optimal solution and exchanging bits (e.g. exchanging a bit of 0 to 1 or a bit of 1 to 0). This is due to the uncertainty of reaching the required solution even after crossover and several iterations. The operator’s process is repeated till the optimal solution is obtained (Mitchell, 1999; Negnevitsky, 2011).

The GA models are used in many applications, such as engineering design optimisation (Roy et al., 2008), maintenance scheduling (Negnevitsky, 2011), financial markets (Mitchell, 1999), and manufacturing (Deb, 2001). However, it is not applicable in this research because there is a need for benchmarking existing practices with the desired best practise, in addition to proposing strategic recommendations, rather than running iterations to convince the user of the optimum solution required.

4.7.3 Artificial Neural Network (ANN)

In order to define ANN, the term *neural network* must be explored. The neural network is basically a model of creating reasoning based on the human brain (Negnevitsky, 2011). It is composed of units (artificial neurons) and interconnections. Basically, the human brain has an estimated 10^{11} units called neurons that are interconnected by 10^{15} links (Munakata, 2008). The architecture design of the biological and artificial neurons and the adopted relationship is illustrated in Figure 4.6.

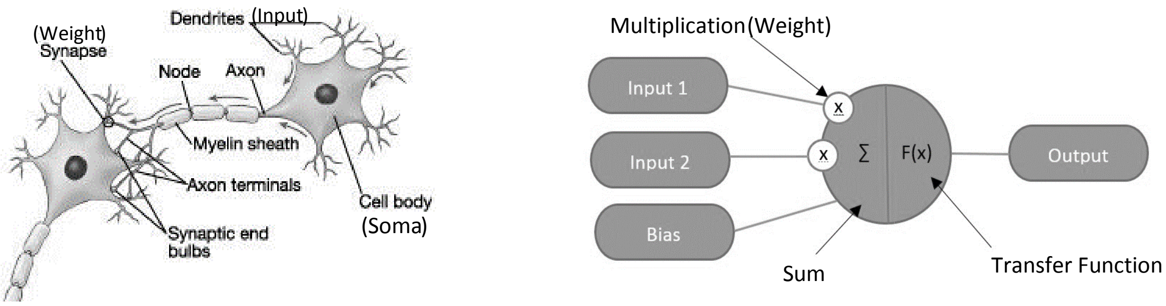


Figure 4. 6 The relationship between biological and artificial neuron, modified from Krenker et al. (2011) and Negnevitsky (2011)

In the case of the biological neuron, the information flows through the dendrite into the neuron, and from the soma (cell body) it is passed via the axon. While in the case of the artificial neuron, the information arrives via inputs, which are weighted individually. After that, the artificial neuron sums the weighted inputs, prioritises them, and processes them with a transfer function. Finally, the processed information is passed through outputs. The interconnections of artificial neurons then form the ANN in a method called topology (Krenker et al., 2011).

To be more practical, the artificial neuron model can be described mathematically by the following function captured from Krenker et al. (2011):

$$y(k) = F[\sum_{i=0}^{m} w_i(k) \cdot x_i(k) + b],$$

where *y(k)* is an output value, $w_i(k)$ is a weight value, $x_i(k)$ is an input, *b* is a bias, and *F* is a transfer function.

Negnevitsky (2011) and Krenker et al. (2011) have defined an ANN as a mathematical model that attempts to simulate the biological neural network. In fact, the main building block of every ANN is the artificial neuron, which represents a function of rules consisting of multiplication, summation, and an activation or transfer function (Munakata, 2008).

In fact, there are only two main types of topologies from which many other possible topologies might be derived. It can be seen from Figure 4.7 that the feed-forward neural network (FNN) type represents the flow of information from input to output in one direction, whereas the recurrent neural network (RNN) is shown in right side and represents the flow of information in the forward and opposite directions.

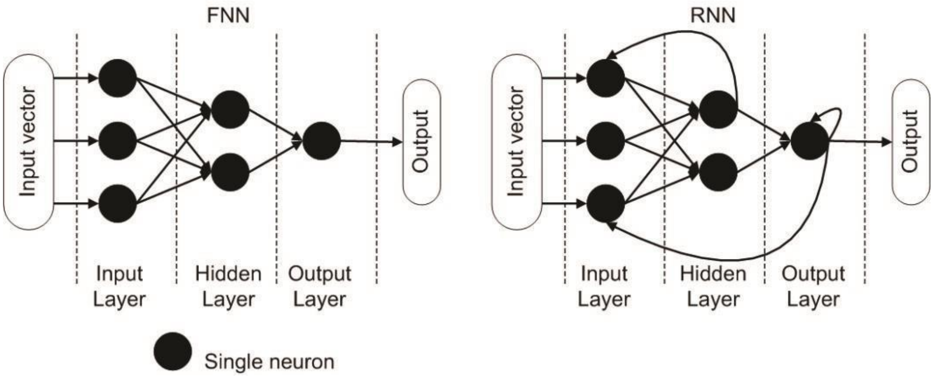


Figure 4. 7 ANN main topologies, Feed-forward (FNN) and Recurrent (RNN), adopted from Krenker et al. (2011)

The investigation into current studies of ANN revealed that enormous trend of optimisation is towards Deep Learning (DL). According to Schmidhuber (2015), DL refers to the use of ANN with several hidden layers in a high dimensional data. He introduced the concept of Credit Assignment Path (CAPs) that could identify whether a given ANN application is of DL or a shallow type.

Fonseca and Cabral (2017) stated that DL using ANN becomes a popular method to extract valuable information from complex datasets; enabling to create complex models better than traditional machine learning techniques. A common example of that is classifying image from the ImageNet dataset (Krizhevsky et al., 2012). For example, an image comes in the form of an array with a pixel value, the first layer of representation shows the image with the presence or absence of edges at particular locations. The second layer identifies motifs by spotting on edges, and the third layer may combine the motifs into parts of familiar objects. Thus, the subsequent layers will be able to detect the main object as combinations of these parts. The key aspect in DL is that these layers of features are learned from data using learning procedure (LeCun et al., 2015).

As the other AI tools, ANN is used in many applications. Before using ANN in a practical field, it must be trained, as it uses a primary set of data or experience to gradually incorporate the knowledge and hence requires adjusting of the weights (Ledesma et al., 2012). Duer (2011) has implemented this technique in assessing the quality performance of a designed repairable technical object in a maintenance environment. Another application targeted the calculation of the energy consumption performance in a supermarket store, which was conducted by Mavromatidis et al. (2013). LeCun et al. (2015) highlighted that natural language understanding is the coming era of applying DL using the ANN technique.

4.7.4 Simulated Annealing (SA)

Munakata (2008) described the SA as a general technique that can be used in many applications for optimisation problems. Moreover, complex optimisation problems are recommended to be undertaken by SA, as the key feature behind this tool is that it always provides a practical solution regardless of whether the solution may not be optimal in some cases (Ledesma et al., 2012).

Aarts et al. (2014: 91) have specified, *“Simulated Annealing belongs to a class of local search algorithms that are known as threshold algorithm”.*

Principally, the concept of an SA optimisation technique came from the analogous meaning of the gradual cooling or the process of driving energy down to a level to obtain a crystal. When metal is heated to a high temperature, it melts. Then, if it is cooled quickly, the molecules will bind together before reaching the lowest binding energy degree and consequently will result in a defective state. This is undesirable in the local minimum requirement of the iterative process. Therefore, in this case, the action to initially set the temperature to high and reduce it gradually till it reaches the crystal state (Munakata, 2008).

As an example of applying SA in the real world, Figure 4.8 is adopted from Ledesma et al. (2012). Their aim was to illustrate how to use SA to optimise a problem by training the ANN. The implementation of SA is divided in three stages: initialisation, perturbation, and error computation. The problem begins (as illustrated in Figure 4.8) when a car needs to travel from the start to the finish positions, passing through points A and B, it should accelerate in some areas and reduce the speed when it turns 90 degrees.

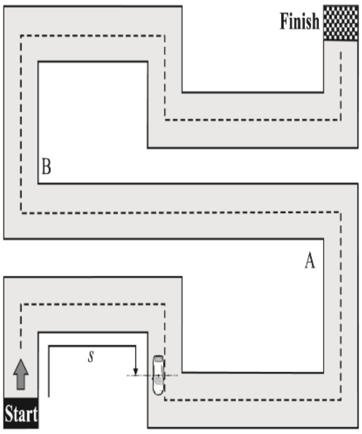


Figure 4. 8 Car and the road, adopted from Ledesma et al. (2012)

Kulkarni and Babu (2005) have proposed an approach using SA to determine parameters related to the quality of products in a continuous casting system. It aims to calculate process parameter values, so that the products will have a negligible chance for defects.

4.7.5 Frame-based System (FBS)

The frame representation is widely used in intelligence systems to efficiently define physical objects and their correlations (Rao et al., 1993). Figure 4.9 is a pictorial of a typical frame of a boarding pass. Principally, as it is shown, the Frame is a data structured with a knowledge acquired from specific concept or object; therefore, frames are used to attain and express knowledge in a frame-based ES. Each frame owns a name and an associated set of slots or attributes, which have their own values (Negnevitsky, 2011). For an OMANAIR boarding pass, for example, the slot flight has the value OM6433 and the slot seat has the value 27A. According to Mohamed (2012), when a slot is a particular object and is filled with a value, it is called an instance-frame, where if it is related to a group of similar objects, it is called a class.

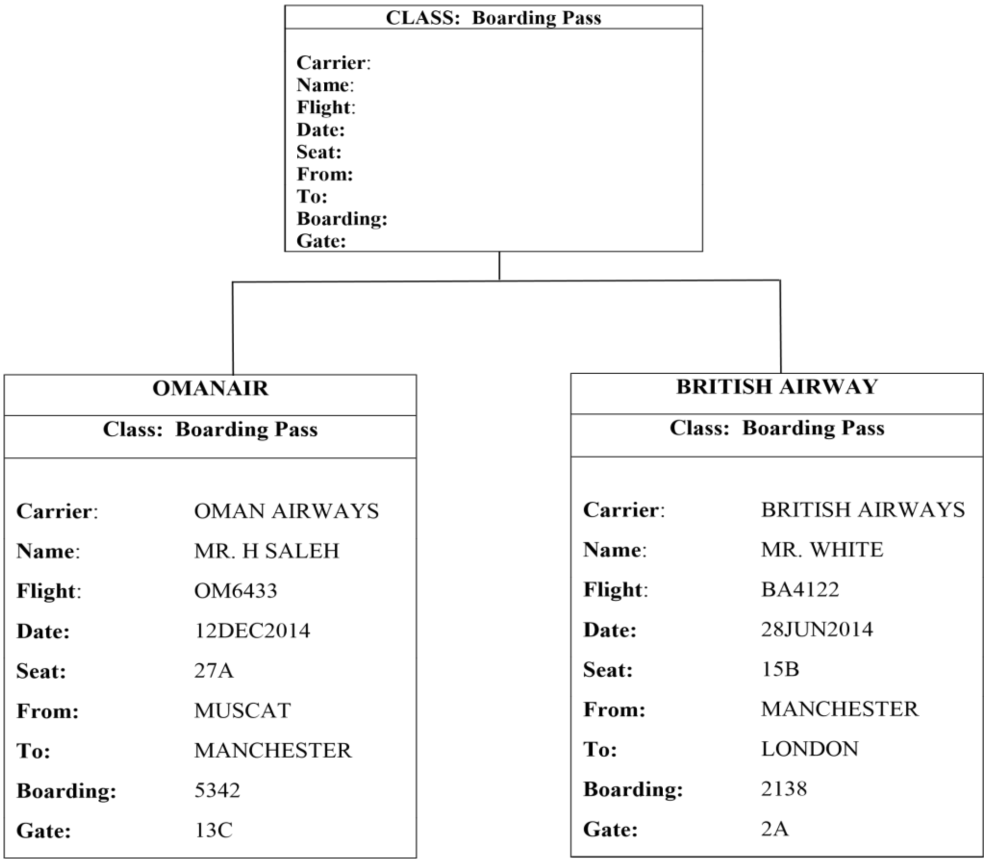


Figure 4. 9 Boarding pass frames

In any FBS, the rules use pattern-matching clauses in order to discover the matching conditions among the instance-frames. This is done through procedures called methods and demons, which aim to add actions to the frames. The method is appropriate if it is required to deal with complex procedures using ‘when changed’ or ‘when needed’ statements, while demons are suitable for if-then statements (Negnevitsky, 2011).

Negnevitsky (2011) declared that frames are used as ES applications in object-oriented programing. This type of programing can be defined as a programming method that uses objects as a source of design, analysis, and implementation. Shiu et al. (1997) explored the reasoning in the frame-based ES by comparing the knowledge base frames with the description of incoming facts, and retrieving the best matching class frame according to the required situation. That is done through an inference mechanism called inheritance.

Further, Karimi and Zand (1998) have worked out the possibility of implementing the strategy of a frame-based knowledge representation in asset-based systems. They have shown that frames can allow data and process modelling integration in asset-based systems, which will lead to reducing data and process redundancy, thus improving maintenance efficiency.

4.7.6 Predicate Logic (PL)

Whenever there is a discussion regarding predicate logic (PL), propositional logic arises. In fact, predicate or first-order logic is an extension of propositional logic. It aims to express human knowledge in a structured way (Yang et al., 2004). Propositional logic deals with facts, such as “Harry is a man”, “John is a man”, and “Robin is a man”. However, if we symbolise their names as *H*, *J*, and *R* for example, the final relationship cannot be declared as a propositional logic, because these letters (i.e. *H*, *J*, and *R*) might have different meanings than only men’s names. Thus, there is a need for quantification knowledge to take over, which leads to PL. Therefore, in reasoning, logic is fundamentally two types, propositional and predicate (Russell and Norvig, 2014).

According to Suber (1997), the quantifiers can identify how many objects are asserted by the predicate. Predicate logic can be first-order logic, second-order logic, or higher-order logic depending on the complexity of the predicate. For example, if the subject is an individual object (like Pele in “Pele is genius”), then it is a first-order logic. However, if there is another predicate (such as being genius in “being genius is risky”), then it is a second-order logic (Suber, 1997).

Ranganathan and Campbell (2003) have verified the effectiveness of applying first-order PL in contextual form by proposing a context model that will help the context-aware applications in its development and ease of deployment.

From a practical perspective, it is known that knowledge representation is very critical nowadays, and the quality of storage and retrieval of such knowledge depends upon its accuracy. Yang et al. (2004) have evaluated PL with other logics (e.g. FL and non-monotonic logic) in five main properties of knowledge base representation: conceptualisation, modification, transfer, decomposition, and integration. The results reflect that FL is much better than PL and non-monotonic in accuracy, while the PL is better in completeness. It has been proven that the PL scope is too narrow; hence, it is not flexible enough to represent natural languages accurately.

4.7.7 Fuzzy Logic (FL)

Fuzzy logic (FL) is a concept that studies principles and methods of human reasoning (Chen and Pham, 2000). Negnevitsky (2011) has clarified that FL refers to a knowledge representation of mathematical principles based on membership degrees rather than the classical binary logic of crisp membership. The degree of truth within the interval (where false = 0 and true = 1) is the main difference between the classical propositions and the fuzzy propositions (Klir and Yuan, 1995).

That degree of membership is driven by fuzzy set boundaries, such as tall, average, and short, which are represented in membership functions in order to be processed later by computer (Negnevitsky, 2011). “*A Fuzzy set is a generalisation of an ordinary set by allowing a degree (or grade) of membership for each element”* (Munakata, 2008: 123).

The FL is based on if-then rule statements, where the *if* part is called the antecedent or premise and the *then* part represents the consequence or conclusion (Maqsood et al., 2010). As there are many examples, the review was conducted to the famous one (see Figure 4.10) that distinguishes the degree of men’s heights.

It can be seen that in classic logic (crisp logic) the degree of membership is either 0 or 1, while in FL the premises (i.e. ‘and’ and ‘or’) are compiled to generate the output value, which represents the degree of height that varies according to a set of rules.

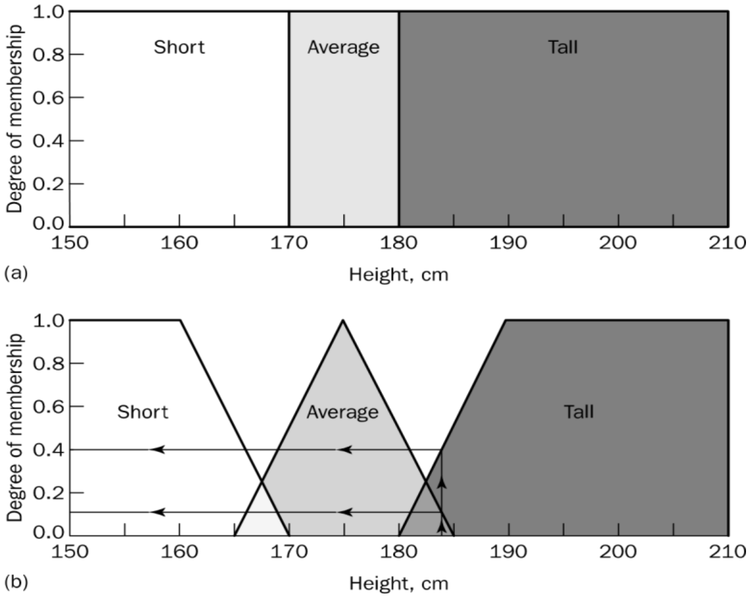


Figure 4. 10 Crisp set (a) and fuzzy set (b) of short, average and tall men, adopted from Negnevitsky (2011)

In a manufacturing environment, knowledgeable workers face uncertainty due to a lack of information given and inaccurate measurements, which leads to quality issues (Yaqiong et al., 2011). According to Munakata (2008), fuzzy systems can be achieved by applying fuzzy logic and fuzzy set principles to areas like a fuzzy ES, where it uses rule based if-then statements. In fact, many applications apply the retrieval of fuzzy information from fuzzy databases in engineering, economics, medicine, and management problems.

On the other hand, Munakata (2008) have explored five major limitations while implementing fuzzy ES: stability, lack of machine learning capabilities, difficulty of tuning the memberships, misconception of the term “fuzzy” by professionals, and the difficulty to verify and validate.

4.7.8 Expert System/ Knowledge Based System (KBS)

An ES or a KBS is one of the AI concepts and methodologies. According to Khan et al. (2011), the terms ES and KBS have the same meaning; therefore, most scholars use them synonymously. When ESs were developed, they contained considerable knowledge regardless of whether it matched with the performance of human experts; therefore, they were called KBSs.

Awad (1996: 3) declared that for the ES, “*the goal is to use specialised languages to design a computer-aided system based on an expert’s thought* *process*". The computer-aided system is the expert system shell that needs to be filled with a knowledge base (KB). This KB contains rules, facts, and the acquired knowledge from human experts (Nawawi et al., 2008). The pictorial shown in Figure 4.11 illustrates the main components of a KBS, which will be discussed in detail.

Today, there is a dramatic increase in using KBSs in various disciplines. The reason is to reduce the high expenditures of hiring experts and to ease the knowledge transfer within an organisation, consequently improving productivity.

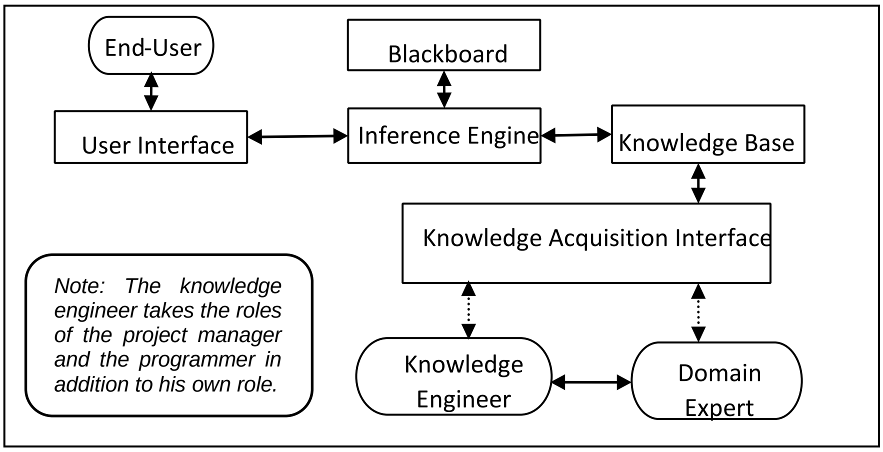


Figure 4. 11 The main components of the KBS, modified from Mohamed (2012)

Expert systems are widely used in manufacturing sectors due to the following main common features (Merritt, 1989):

a. User friendly (easy to use).
b. Dealing with uncertainty, where reasoning can justify imprecise data and rules.
c. The ability of the system to explain and recommend solutions.
d. Using forward and backward chaining techniques, which will be highlighted later.
e. Effective data representation.

According to Negnevitsky (2011), ESs use symbolic reasoning to represent knowledge (i.e. facts, concepts, and rules). Unlike conventional systems, which deal with numeric data, ESs are built to deal with knowledge (qualitative and quantitative data) processing.

Knowledge base systems have been used to investigate water quality (Chau, 2007), performance measurements (Khan and Wibisono, 2008), the system advisory of ISO 9000 (Khan and Hafiz, 1999), planning and designing of a flexible manufacturing system (Khan et al., 2011), and operation and maintenance strategies (Milana et al., 2014) to name but few.

4.7.8.1 End User, Knowledge Engineer, and Domain Expert

Generally, in order to develop an ES, five members have to exist: the project manager, the knowledge engineer, the programmer, the domain expert, and the end user. Depending on the size, criticality, and complexity of the ES, the roles of the project manager and the programmer might be tackled by the knowledge engineer (Negnevitsky, 2011). This research focuses on the members who are involved as part of the user interface assuming that the knowledge engineer has the roles of project manager and programmer in addition to his or her own roles. This can be illustrated as shown in Figure 4.11.

The knowledge engineer is the leader who manages the system from the planning stage to implementation and future maintenance or upgrading. He or she is the system developer who seeks a problem domain to be structured and solved by involving experts (Mohamed, 2012). The knowledge engineer utilises the knowledge of written documents (e.g. manuals) and converts it into a KBS with the help of experts. Wagner (2017) categorised the content analysis of the survey of 311 ES applications into three main areas of problem domain based on Clancey (1985):

a. Analysis problems (e.g. diagnosis, classification, interpretation, and debugging).

b. Synthesis problems (e.g. designing, planning, scheduling, and configuration).

c. Combination problems (e.g. prediction, monitoring, instruction, command and control, and repair).

The domain expert is the skilled and knowledgeable person who is able to solve problems within that particular domain. According to Negnevitsky (2011), the domain expert is the most important player in the development team and, therefore, must be willing to participate and put a substantial amount of time in for this project. The end-user is any person who can use the KBS after the implementation (e.g. a senior technician, a manager, or a quality controller). In fact, the end-user can be anyone who may benefit from the system.

These members communicate with the system through a user interface. Liao et al. (2004) stated that the user interface determines whether this communication contains answers in the form of yes or no, filling forms, or selecting items from menus. In addition, it roles the degree of providing explanations for solutions or assisting the end-user. Therefore, in designing the user interface, the knowledge engineer must focus high attention on the screen display and the user interaction with input devices (Nawawi, 2009). According to Awad (1996), the ES becomes a “black box” if there is no user interface, which means that the system will be unable to discover the information needed to conclude the process.

4.7.8.2 Knowledge Base (KB)

Awad (1996) has declared that the KB is a storage of facts and rules acquired from experts. Khan and Hafiz (1999) highlighted the most important knowledge representations, which are the production rules, semantic network (collection of items having links to show their relationships in the KB), frames, and predicate calculus. As most ESs use production rules, they been called rule-based systems, where the rules are divided into two general types (Awad, 1996):

a. Definitional rules, such as

IF *the home state is Bradford*
THEN *the country is the United Kingdom*

b. Heuristic rules, such as

IF *the equipment major overhaul is not attended*
AND *the maintenance is bad*
THEN *the equipment will break down*

4.7.8.3 Inference Engine

The inference engine is the backbone of the KBS, where the reasoning and solution triggering process takes place. According to Awad (1996), it is a cluster of computer programs that uses the rules of the KB to coordinate between reasoning and inference in order to come up with a solution. If no solution can be reached, the system may provide an answer with a qualifying certainty factor. Khan and Hafiz (1999) emphasised that the inference engine is just an ES without knowledge, it manipulates the knowledge represented in the KB using algorithms. It is categorised in two different ways, according to problem solving approaches: forward chaining and backward chaining (Liao et al., 2004).

a. *Forward chaining* is an approach that starts with known data and goes forward seeking a conclusion or new information; therefore, it is also called data driven (Awad, 1996).

b. *Backward chaining* is an approach also known as goal-driven; therefore, it starts with a goal as a hypothetical solution, and the role of the inference engine is to find evidence to prove it (Negnevitsky, 2011).

The pictorial shown in Figure 4.12 represents forward and backward chaining.

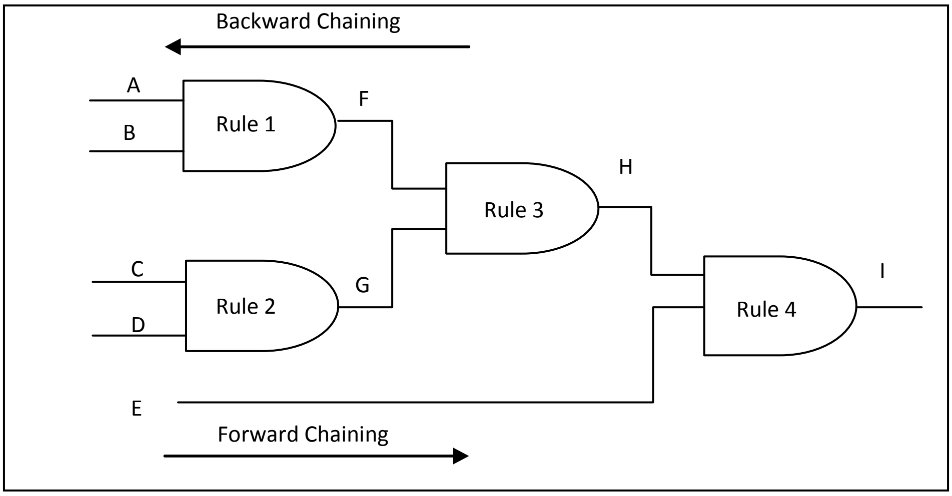


Figure 4. 12 Forward and backward chaining, adopted from Mohamed (2012)

From the above figure, by implementing if-and-then statements, it can be seen that the initial facts in the forward chaining are A, B, C, D, and E. Therefore, the required answer (i.e. I) can be achieved. In backward chaining, the process begins with the solution I and goes backward to discover the initial facts.

4.7.8.4 Blackboard

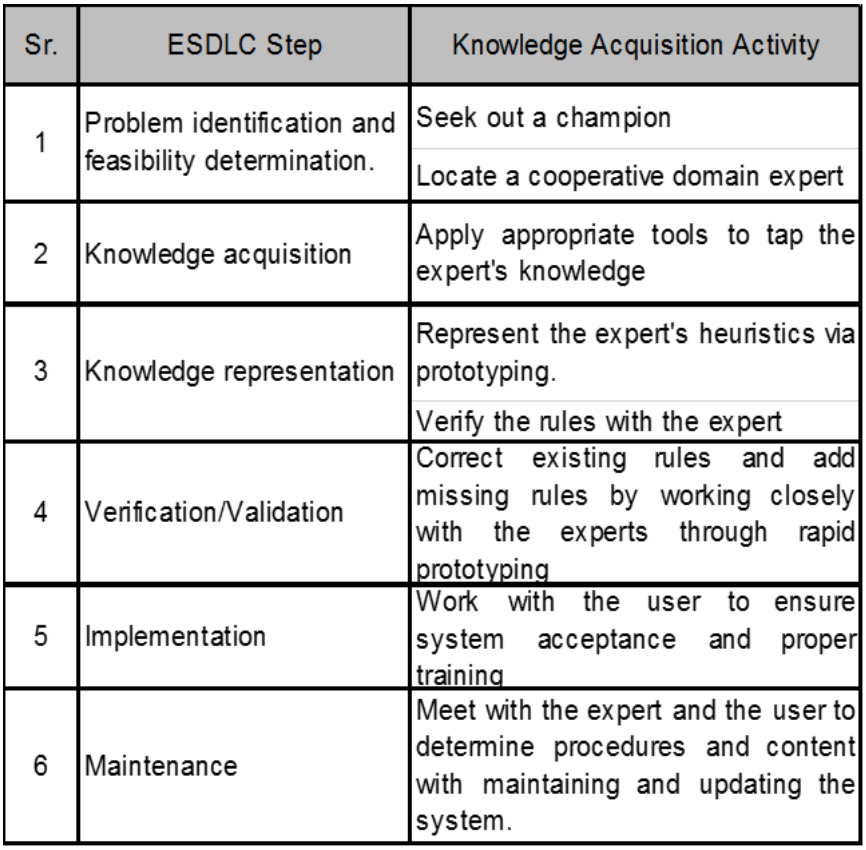
According to Nawawi (2009), the blackboard is a working memory area, which gives a description of the current problem related to the user input data. It is similar to the computer hardware concept of random access memory (RAM). Essentially, the blackboard system is a middleware in a hybrid system. It is a common data structure, which is the link between knowledge sources in order to share information. Therefore, it acts as a global store of the input data, variables, and the final solution (Chau and Albermani, 2005). Using the blackboard, there will be equal opportunities for the experts to propose a solution before processing the final solution (Mohamed, 2012). The blackboard contents change according to the complexity of the problem domain and situations.

4.7.8.5 Knowledge Acquisition Subsystem

According to Awad (1996), human participation in KBS is divided into two parts; the first part is related to non-expert users who seek a solution in a particular domain, and the second part is in the process of knowledge acquisition.

Knowledge acquisition includes many sources, such as experts' interviews, observations from experts' work lives, and published cases (Nawawi, 2009). Awad (1996) has represented the role of knowledge acquisition in various steps of the ES development life cycle (ESDLC), where it shows that it is a front-end step. This can be illustrated in Table 4.4, in identifying feasibility, selecting an appropriate expert, recording an expert's knowledge, plugging in the gaps, verifying and validating the rules, and finally repairing and upgrading the system.

Table 4. 4 Knowledge acquisition activities in the ESDLC, adopted from Awad (1996)



Sr.	ESDLC Step	Knowledge Acquisition Activity
1	Problem identification and feasibility determination.	Seek out a champion
		Locate a cooperative domain expert
2	Knowledge acquisition	Apply appropriate tools to tap the expert's knowledge
3	Knowledge representation	Represent the expert's heuristics via prototyping.
		Verify the rules with the expert
4	Verification/Validation	Correct existing rules and add missing rules by working closely with the experts through rapid prototyping
5	Implementation	Work with the user to ensure system acceptance and proper training
6	Maintenance	Meet with the expert and the user to determine procedures and content with maintaining and updating the system.

Wagner (2017) declared that the most common knowledge acquisition techniques are the following: structured interviews, unstructured interviews, psychological scaling, card sorting, and protocol analysis. All of these techniques require that the expert and the knowledge engineer are skilled enough in order to succeed.

4.8 Uncertainty

According to Liu (2012: 4), "*If it happens that some phenomenon can be quantified by uncertain measure, then we call the phenomenon uncertainty",* or the phenomena that can be quantified by uncertain measure. Hopgood (2011) described three main sources that cause uncertainty; he stated the need to define a rule in a system as follows:

a. uncertain evidence (Perhaps it is not certain that Joe will visit us today)

b. uncertain links between evidence and the conclusion

(It is not certain that the motor will breakdown; however, it has an abnormal vibration)

c. vague rule (What is an "abnormal" vibration?)

Sources (a) and (b) are recommended to be handled by Bayesian updating, while source (c) must be solved through fuzzy logic, which has been discussed earlier. To examine the following rule which relates to a steam boiler:

IF steam is escaping, THEN the steam outlet is blocked.

Previously, if there is a blockage in a steam outlet and there is no evidence, the hypothesis could be treated as false. When there is no evidence of blockage, the Bayesian methodology assigns a probability to the hypothesis that the steam outlet is blocked. This probability is updated by the Bayesian updating technique against the hypothesis. Therefore, for the rule above, it has been assumed a certainty of outlet blockage if there is a steam escaping. However, this assumption will act as supporting evidence only, and the Bayesian technique will update the probability of the hypothesis through new evidence each time, which will lead to an optimum situation (Hopgood, 2011).

In order to update the probability (*P*) of a hypothesis (*H*) for the new evidence (*E*), the following formula is used, according to Hopgood (2011):

$$P(H|E) = \frac{P(H)*P(E|H)}{P(H)*P(E|H)+P(\sim H)*P(E|\sim H)}$$

Where ~*H* = not *H*, the probability of ~*H* = *P*(~*H*) = 1 – *P*(*H*), *P*(*H*) = the current hypothesis probability, *P*(*E*|*H*) = conditional probability that evidence exists with a true hypothesis, and *P*(*E*|~*H*) = uncertain probability that evidence exists with a false hypothesis.

Many methods can be applied in order to distinguish and classify uncertainty. If the cause of uncertainty is randomness, then it is called *aleatoric uncertainty*, which can be described with stochastic models. However, if the cause of uncertainty is due to subjective and objective factors, then it is called *epistemic uncertainty*, which can be described using fuzziness and interval models (Möller and Reuter, 2007).

According to Birge and Louveaux (2011), the stochastic model is used in wide application areas, where efficiency and profitability are essential. They have given practical case studies for some applications using this model; for example, it can be used in the design stage to implement quality control of a manufacturing product. In fact, they claim that the Taguchi method can be dealt with as a type of stochastic programming.

Soize (2012) has proposed a probabilistic approach to uncertainties through computational models, which contrasts in concept with Liu (2012), who contrasts with many other scholars who are dealing with a degree of belief in uncertainty as a subjective probability. Liu (2012) claims that the probability theory in this case may lead to counterintuitive results, which are unsuitable for the theory itself. This might be obvious if there is a very small sample (or no sample) for the probability distribution to be estimated. Domain experts will evaluate the degree of belief of each event, where they usually over-weight the unlikely events. Consequently, there will be a larger variance than real frequency, and hence the probability theory is not valid. On the other hand, the probability theory is applicable for a large sized sample. According to Li and Du (2007), the study that was conducted by professor Kahneman (the winner of the Nobel Prize in economics, 2002) proved that human decision-making under uncertainty, based on small samples, will deviate systematically from the basic probability theory. In addition, decision makers seem to depend on the differences between their expectations and the results obtained rather than the results itself. That will lead to a long, open debate between probability and uncertainty.

This research will not use any of the above techniques to overcome uncertainty in the KB rules, but using Explanation facility which contains clear description of the key rules with additional knowledge.

4.9 Applications of AI in Building Maintenance

Literatures show that AI has been used widely in building maintenance. This has focused mainly in managing technical data that relates to retrieve old cases of building maintenance tasks and suggest an optimal remedial action. For example, Gajzler (2010) developed a repair advisory system tool that acts as a knowledge base decision support system for concrete defects in building maintenance.

Fong and Wong (2009) proposed a web-based prototype system that aims to store and retrieve knowledge and experiences on solutions to building maintenance problems. The system is designed to capture more specific rules related to building maintenance, because the research survey revealed that building maintenance knowledge cannot be generalised. It was noted that users will be allowed to share experiences with professionals for the sake of facilitating decision-making processes. They declared that building maintenance experiences might include the awareness of the nature of repair, response time, project location, performance over time, suppliers and contractors' details, health, and safety.

Almarshad et al. (2010) created a knowledge management (BIM) application within a building maintenance environment in Kuwait. The system aims to connect thoughts and experiences of maintenance technical teams in different branches, which will reflect back to improving workforce performance. Although it aims toward a building maintenance knowledge base, this study has been further developed to achieve dynamic acquisition of technical data from the maintenance controller.

Gajzler (2013) reviewed a repair advisory system tool that acts as a knowledge base decision support system for building maintenance. In fact, the system was developed by Gajzler (2010) and designed to investigate industrial concrete flooring defects and recommend the optimal repair solution. Obviously, it can be seen that both papers have focused only on concrete defects.

Motawa and Almarshad (2013) embedded building information modelling (BIM) with case-based reasoning (CBR) in order to develop a knowledge base system that can retrieve old maintenance defect solution cases. The system uses the nearest neighbour technique to select the best matching cases based on similarity scores. Along the same line, Dukić et al. (2013) proposed a building data management software application that can assist in mapping and planning building maintenance activities according to building type and related possible defect/maintenance tasks.

Chang and Tsai (2013) developed a knowledge base system that interlinks building health facility indexing records with related analysis in a system called the

Building Diagnosis Navigation (BDN) system. The idea of the BDN system is to extract the technical maintenance knowledge from previous work order reports and assist decision makers by recommending immediate solutions to a current problem. In fact, this approach can be achieved by adopting the CBR methodology, which was obviously performed by Motawa and Almarshad (2013). However, none of them have shown any integration of maintenance activities with a solid quality concept.

In this research, the KBS is selected to support the planning, designing, and implementation stages of Lean6-SBM System development. Nawawi (2009) and Mohamed (2012) stated that many software and commercial shells are available for developing organisation decision making process with the support of AI KBS technique. Therefore, the development of KBS is easier compared to other AI techniques and methodologies because the knowledge obtained from literatures, experts, and users are easily structured in a rule-based system.

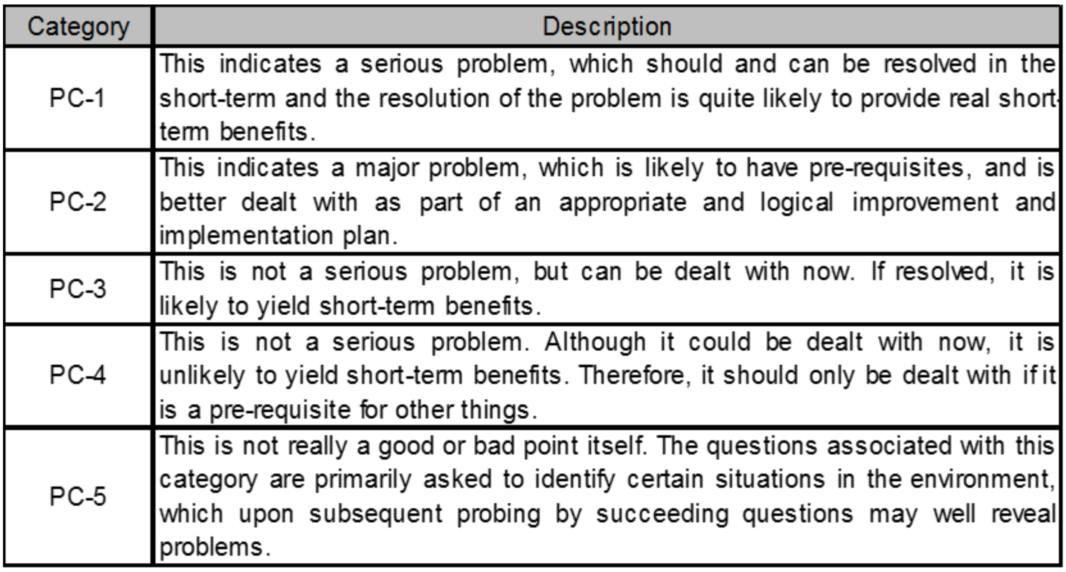
4.10 Gauge Absence Prerequisite (GAP)

Gauge Absence Prerequisite (GAP) is a benchmarking tool that will be used in the KB lean six sigma sustainable building maintenance (Lean6-SBM) system. According to Nawawi et al. (2008), it will benchmark the current situation of the company with the desired future situation in order to estimate the performance gap between them.

Khan and Hafiz (1999) listed some generic objectives of a GAP analysis. It can help in organising the action list per priorities, identify high-level issues from low-level issues, identifying weaknesses and strengths in current practices, and providing a quantitative basis of the existing system to be compared with the effective functioning. In addition to that, it can identify the main issues that act as critical failure factors to effective implementation.

In order to achieve an optimum benchmarking process, GAP has been designed so that it detects the level of absence of any prerequisite condition from the most importance for system sustainability to the lowest (Kochhar et al., 1991). This can be described as shown in Table 4.5. The details regarding integrating GAP with Lean6-SBM are discussed in Chapter 5.

Table 4. 5 Problem Categories (PCs) of GAP analysis (Udin et al.,2006)



Category	Description
PC-1	This indicates a serious problem, which should and can be resolved in the short-term and the resolution of the problem is quite likely to provide real short-term benefits.
PC-2	This indicates a major problem, which is likely to have pre-requisites, and is better dealt with as part of an appropriate and logical improvement and implementation plan.
PC-3	This is not a serious problem, but can be dealt with now. If resolved, it is likely to yield short-term benefits.
PC-4	This is not a serious problem. Although it could be dealt with now, it is unlikely to yield short-term benefits. Therefore, it should only be dealt with if it is a pre-requisite for other things.
PC-5	This is not really a good or bad point itself. The questions associated with this category are primarily asked to identify certain situations in the environment, which upon subsequent probing by succeeding questions may well reveal problems.

The GAP has been integrated with hybrid KBSs as a benchmarking tool in some areas, such as supply chain management (Udin et al., 2006), performance measurement systems (Khan and Wibisono, 2008), lean manufacturing (Nawawi et al., 2008), low volume automotive (Mohamed and Khan, 2011), and maintenance strategy and operation (Milana et al., 2014).

4.11 Analytic Hierarchy Process (AHP)

The AHP approach has been used widely as a multi-criteria decision-making tool since the initial development by Thomas Saaty in 1971 (Satty, 2008). In this research, and due to the complexity of the conceptual integration between Lean and Six Sigma, it appears to be the best tool. Chan et al. (2006) clarified that AHP, as a measurement theory, can deal with tangible and intangible factors. Therefore, it allows quantitative and qualitative attributes to be evaluated. They proposed that the overall priorities of criteria (i.e. main criteria and sub-criteria) are combined to establish alternative decisions.

Saaty (2008) has designed the AHP decision-making methodology by putting forth the following implementation steps:

a. The problem must be identified, and knowledge acquisition must be determined.

b. The decision hierarchy must be structured so that the goal will be on top, followed by broad objectives, intermediate (subsequent element criteria), and finally, the set of alternatives on the lowest Level.

c. Pair-wise comparison matrices sets must be constructed; upper Level elements are compared with the ones immediately below.

d. The priorities of the lower Level will be weighted by the priorities obtained from the comparison above.

e. Step (d) to be repeated for every element.

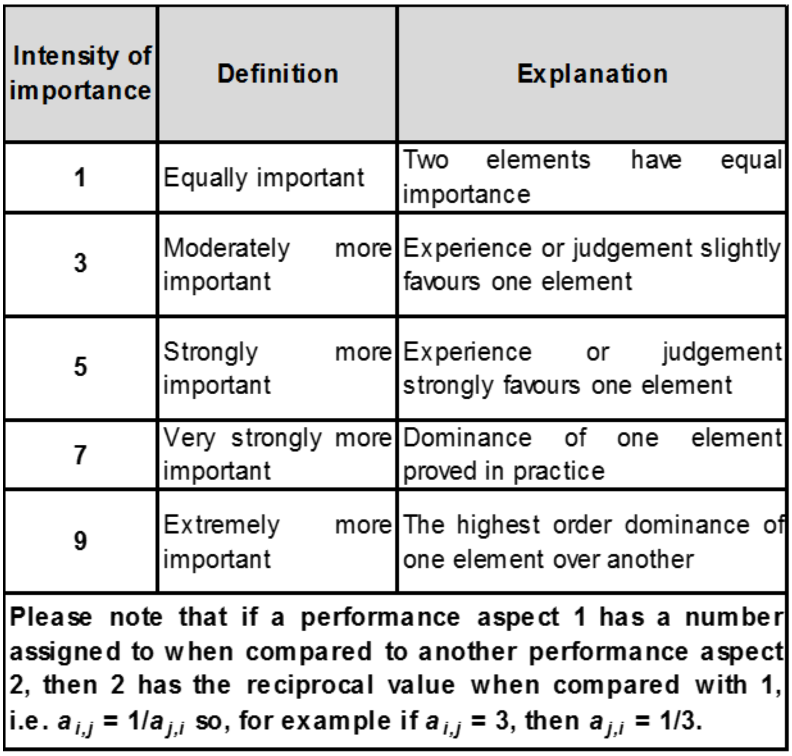
f. The weighted values must be added for each element and the overall priority is obtained.

g. Continue the processes (d, e, and f) until the final priorities of the alternatives in the bottom Level are achieved.

Wong and Li (2008) described some advantages of AHP. They elaborated that it can organise the problem critical aspects in a family tree format, which helps in the ease of handling. They mentioned that it deals with pair-wise comparisons, which allows derivation of the weights of criteria and alternative scores from comparison matrices rather than directly quantifying weights/scores. They insisted that it is the most powerful multi criteria decision-making (MCDM) tool that can measure the consistency in judgments.

The pictorial shown in Table 4.6 represents the classical AHP protocol weighting criteria assigned according to importance from 1 as equally important to 9, which tags the most important criteria.

Table 4. 6 Illustration of the weighting in AHP, adopted from Hopfe et al. (2013)



Intensity of importance	Definition	Explanation
1	Equally important	Two elements have equal importance
3	Moderately more important	Experience or judgement slightly favours one element
5	Strongly more important	Experience or judgement strongly favours one element
7	Very strongly more important	Dominance of one element proved in practice
9	Extremely more important	The highest order dominance of one element over another
Please note that if a performance aspect 1 has a number assigned to when compared to another performance aspect 2, then 2 has the reciprocal value when compared with 1, i.e. $a_{i,j} = 1/a_{j,i}$ so, for example if $a_{i,j} = 3$, then $a_{j,i} = 1/3$.		

Wong and Li (2008) have applied AHP in assisting decision makers in how to analyse and select intelligent building systems. Their findings revealed that maintenance cost was perceived as the most important sub-criteria (under the main criteria 'cost effectiveness').

AHP has been used for many quality and maintenance related applications. For example, it has been used to set the priorities of fire safety attributes in a building facility management system (Lo et al., 2000). Moreover, Badri (2001) applied AHP to produce a decision making tool using sets of service quality attributes. In manufacturing, Nawawi et al. (2008) applied AHP as a prioritisation tool in a Lean manufacturing management system, and Mohamed and Khan (2012) utilised it for the sake of a low-volume automotive manufacturing system. Lin et al. (2012) proposed a theoretical framework to determine the best procurement strategy for the maintenance management of a particular building by using AHP. Sugumaran et al. (2011) extended the use of AHP with TPM and Quality Function Deployment (QFD), which was later justified by Singh and Ahuja (2012). Moreover, it has been further investigated and validated by Sugumaran et al. (2014). Last but not least, Milana et al. (2014) applied AHP to improve maintenance strategy and operation.

Therefore, it can be seen that the AHP methodology will play a major role in implementing the KB Lean6-SBM, by optimising the recommended solutions to the decision maker from a priorities point of view.

4.12 Summary

This chapter has defined the DIKW framework hierarchy of knowledge creation and implementation. The formulations of the DIKW hierarchy suggested by scholars demonstrates a common view, where the key elements are the same and arranged in a similar order. Real industry examples have been reviewed while exploring the overlap between the framework elements. These elements are then analysed and critiqued based on extensive reading.

Next, seven AI concepts and methodologies are explored that are used in various applications to solve different types of problems, according to the problem domain complexity and certainty. These concepts are case-based reasoning (CBR), genetic algorithms (GA), artificial neural networks (ANN), simulated annealing (SA), frame-based system (FBS), fuzzy logic (FL), and knowledge based systems (KBS)/expert system (ES). The reason for revising all of these AI methodologies was in order to select the most relevant for this research.

From all of these studied AI concepts, the most relevant concept suitable to be used in maintenance and quality management applications is the KBS, which will be the driving tool/methodology for the new application (Lean6-SBM). It has been noted the widely use of KBS in manufacturing sectors. This was due to some common features like easy to use, the ability to deal with uncertainty, the ability to explain and recommend solutions, and the effective data representation. It has been described that KBS problem domain can be categorised into one of the three main areas: analysis problems, synthesis problems, or combination problems. The main components of the KBS have been described.

Uncertainty is one of the critical areas that was discussed. To overcome uncertainty, it was justified that this research will utilise the feature of providing explanation facility rather than using other techniques like FL, PL, or Bayesian logic. The explanation facility has the flexibility of adding extra knowledge that describes the logic behind each and every aspect within the knowledge base according on the benchmark standards.

Finally, the chapter has also explained two other methodologies, Gauge Absence Prerequisite (GAP) and Analytic Hierarchy Process (AHP), which will be integrated with the KBS. These two methodologies have been successfully integrated in previous applications. Further details are discussed in Chapter 5.

CHAPTER 5

Conceptual Framework of Integrated Lean Six Sigma Maintenance System for Sustainable Buildings

5.1 Introduction

This chapter intends to present the second and third objectives of the research; the design of the KB Lean6-SBM model for integrated Lean Six Sigma Maintenance for Sustainable Buildings, and the converting of this model into a framework and a structured hierarchy format. Hence, this chapter illustrates the generating process of the conceptual framework for Lean6-SBM. The framework promotes Lean and Six Sigma as the pillars of Lean6-SBM, which are developed to be incorporated in a practical way to serve SBM. The systematic steps for the framework development are shown in Figure 5.1.

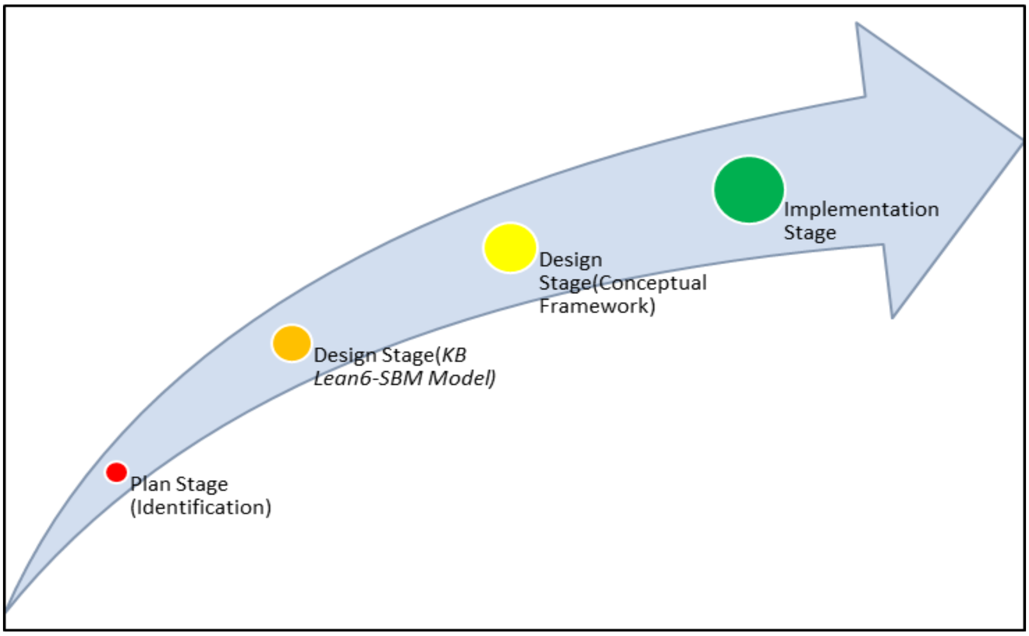


Figure 5. 1 The Conceptual Framework Development Steps

Essentially, this research focuses on proposing a generic framework for KB Lean6-SBM because there is no current solid framework that addresses the issue of implementing LSS in SBM. Moreover, this chapter will detail the process of implementing the proposed conceptual framework by converting it into a structured model based on hierarchal decision-making Levels. This will help create the necessary modules that will be used to generate the KB rules which will assess the elements of Lean6-SBM with the support of KB capabilities.

5.2 The KB Lean6-SBM Model

Based on the diagram in Figure 5.1, the framework development steps start with planning. Litvaj and Stancekova (2015) cited the importance of having five major steps for optimising the decision-making process. These start with identification of the problem followed by preparation of its variants, selecting the most appropriate alternatives, introducing them into action rules, and finally controlling the process. Therefore, it is essential in development of the *Planning Stage* to look for the different attributes that affect the main target. The literature review found that failure to implement LSS might cause a catastrophic impact on the organisation’s resources. Thus, for the purpose of this research, and in order to have a smooth implementation, the KB Lean6-SBM model is designed to serve three main stages: Planning, Designing, and Implementation.

The essential elements of Lean6-SBM have been surveyed in Chapter 2 and Chapter 3 of the literature review. The information obtained will be interpreted into a KB. These accommodate the aspects of SBM, and LSS. In fact, this KB will be utilised as the base of the Lean6-SBM conceptual framework. In addition, the KB Lean6-SBM model will review other general elements such as organisation environment, financial and market analysis prior to applying the change management readiness test.

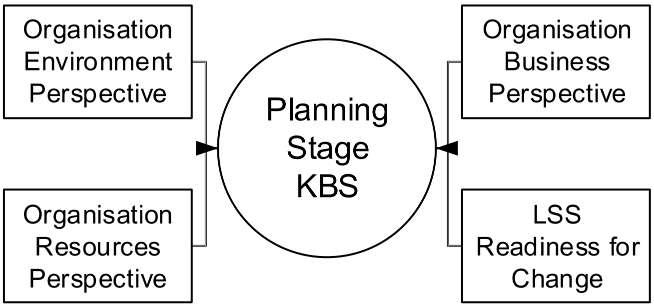


Figure 5. 2 KB Lean6-SBM model (Planning Stage)

The first two stages in the KB Lean6-SBM model are planning and designing which represent the strategic Level, followed by the *Implementation Stage* which demonstrates the execution/operational Level. As can be seen in Figure 5.2, the *Planning Stage* acts as the starting point from which the organisation's profile, status, and general statements must be identified. According to Aldairi et al. (2016), four major sets of information need to be considered in the *Planning Stage*: *Organisation Environment Perspective, Organisation Business Perspective, Organisation Resources Perspective,* and *LSS Readiness for Change*. For the business perspectives, a general information about the company/organisation environment, market analysis, and financial analysis is required to identify a manufacturing business (Udin et al., 2006; Taylor and Taylor, 2008).

Despite the different cultures, pressures, and reasons for change in organisations, change management frameworks play an important role in minimising the distractions and impacts by keeping any change effort under control (Kotter, 2011). Thus, this research has proposed an *LSS Readiness for Change* framework based on critical elements identified from the literature review and based on an existing change management framework. This will evaluate the organisation's readiness from ICT, Share Values, and Soft TQM perspectives. These might overlap in some aspects with the assessment of the *Organisation Resources Perspective,* however, both supplement each other in order to have a comprehensive overview of the organisation's capability towards implementing LSS.

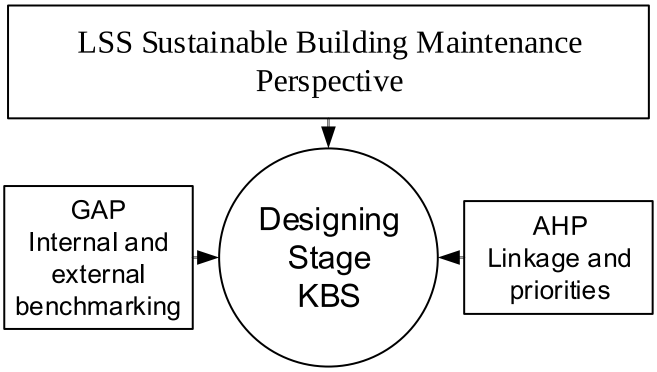


Figure 5. 3 KB Lean6-SBM model (Designing Stage)

In the *Designing Stage*, the information will be used to find the combination of SBM functions and the quality aspects required to run the business (Figure 5.3). For both, SBM and LSS, it is necessary to consider sustainability metrics (*LSS Sustainable Building Maintenance Perspective*). These must integrate social, environmental, and economic impacts within the selected SBM and LSS performance measures. Accordingly, the conceptual design will consider the most suitable LSS elements with respect to SBM in order to generate Lean6-SBM. Next, Lean6-SBM has to be supported by a decision-making process to finalise the application conceptual design. This requires having a powerful methodology that can trigger two deliverables in KB Lean6-SBM: the benchmarks between the existing practices and the desired ones, and listing the recommended solutions based on priorities. The literature review has shown a wide use of GAP and AHP techniques in such an approach with declarations of successful implementations. This has directed the research objectives by embedding both techniques into the KB Lean6-SBM model. At the end, the *Implementation Stage* will be shown as a continuous process to ensure the benefit of each step.

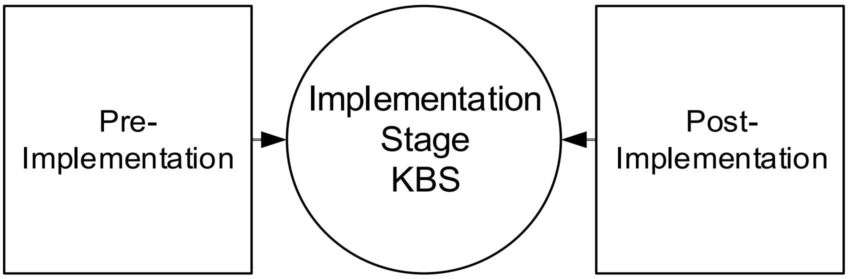


Figure 5. 4 KB Lean6-SBM model (Implementation Stage)

Figure 5.4 shows the *Implementation Stage*, which illustrates the third part of the KB Lean6-SBM model. In fact, the model was consistently reviewed with the research supervisors, senior maintenance engineers, and LSS Black Belt and Master Black Belt practitioners. The review by these experts has been extended to ensure the critical selection of the KB key performance indicators (KPIs) and the related development steps as part of the verification and validation process.

5.3 The Conceptual Framework

Based on the driven KB Lean6-SBM model (Aldairi et al., 2016), and in order to formulate the Lean6-SBM in a rule-based system, the researcher has contributed to the modules (LSS Readiness for Change, LSS Sustainable Building Maintenance Perspective, and DMAIC Implementation) and related sub-modules by developing the detailed structure with the flow of information at each stage to form the suitable conceptual framework as shown in Figure 5.5. On the other hand, the modules (Organisation Environment Perspective, Organisation Business Perspective, and Organisation Resources Perspective) are adopted from Udin et al. (2006), Nawawi et al. (2008a), Mohamed and Khan (2012), and Milana et. al. (2014a). However, even in these modules, the KB rules are developed by the researcher and are quite different from the aforementioned authors' work.

These modules will be utilised to generate the KB rules for different variables of LSS in SBM based on organisational hierarchy Levels of decision-making. Finally, the rules will be stored in the KB database and facilitated by integration with the GAP analysis methodology to achieve optimal analysis and assessment outcomes of the decision-making process. The design of the framework is set to assess the organisation's capabilities in different perspectives, starting from a broad strategic Level and narrowing down to the most operational Level. As the study is targeting the implementation of LSS in the SBM context, it is necessary to study critical success factors and critical failure factors of implementing LSS in a similar environment. From the extensive literature review and discussion with LSS practitioners, it is found that the common factors that affect such implementation are the 3Cs driven by Oakland (2014): commitment, culture, and communication. These soft factors have to be addressed before giving a decision to implement LSS. Thus, it has been found that the SBM organisation has to be assessed initially through a readiness test framework. This has to be integrated in the *Planning Stage* of the KB Lean6-SBM, after the identification of the organisation environment and its resources capabilities.

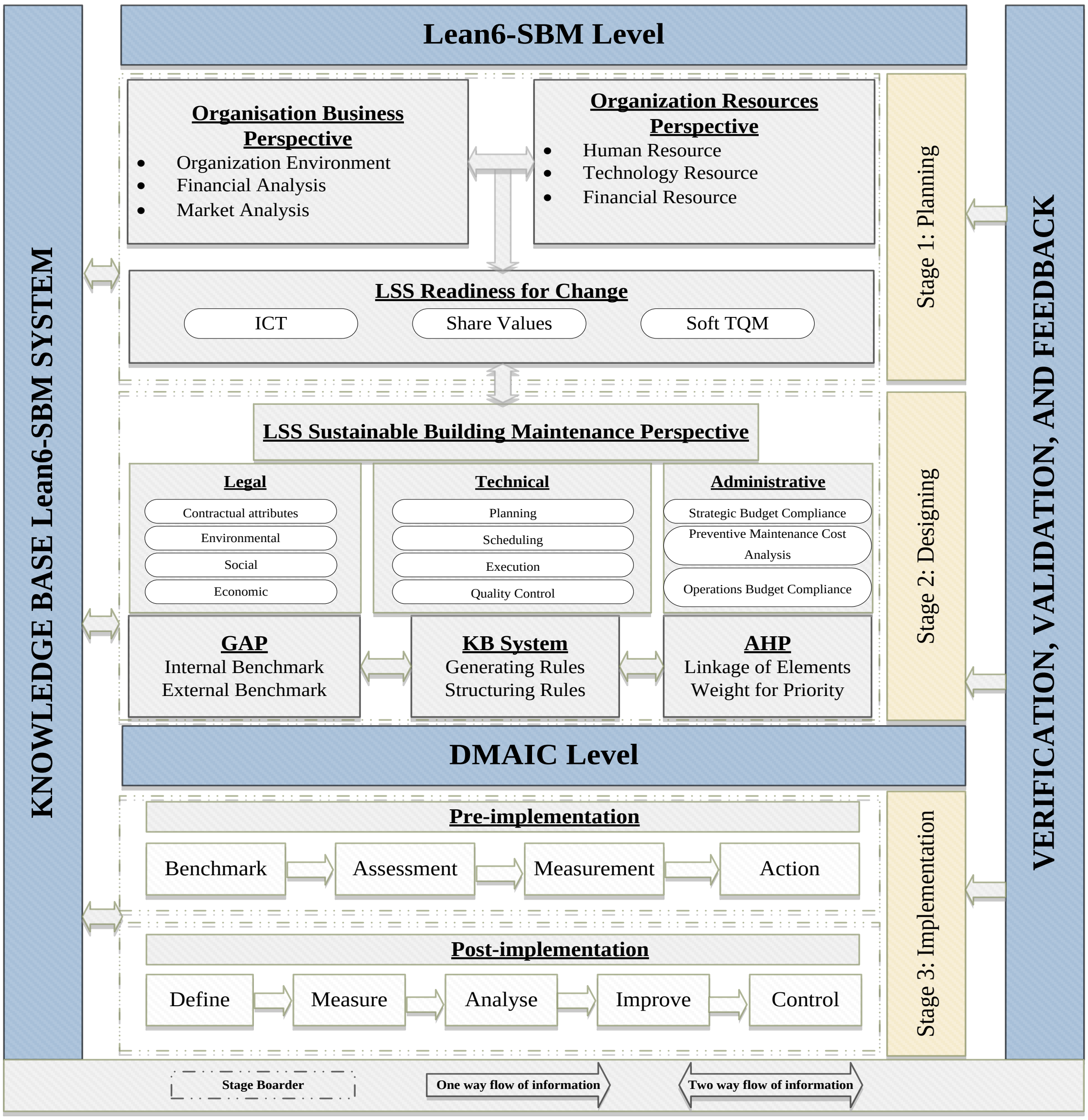


Figure 5. 5 Conceptual Framework of KB Lean6-SBM

To ensure achievement of the main objectives of the study, it is very important for the organisation to truly commit its mission towards improving environmental performance. Therefore, it must consider the integration of environmental aspects in the operation and decision-making. The next stage within the framework is the *Designing Stage*. This stage has been designed to incubate the environmental sustainability aspects within a sustainable building maintenance taxonomy. The assessment starts with *Legal* aspects in which contract condition is supported by the green/environmental national strategies, statutory requirements, consistency, and stability of contract forms. Furthermore, evaluation will include how efficient the organisation's sustainability metrics are by assessing the use of energy and water resources, waste management, health and safety, and the organisation's ethics towards corporate social responsibilities (CSR).

With respect to *Technical* aspects, there will be evaluation of the work orders' life cycle process. This will cover the four main activities in the preventive maintenance strategy: *Planning, Scheduling, Execution, and Quality Control*. These will be assessed based on availability of code of practices, fulfilment of responsibilities, and how the maintenance teams perform their daily preventive maintenance activities. These include, but are not limited to, the effectiveness of planning, scheduling, executing, and quality control departments. The final assessment in SBM relates to *Administrative* aspects. In these aspects, the KB Lean6-SBM will assess the commitment towards budget compliance and how efficient the organisation's preventive maintenance cost analysis is.

The integration of LSS in SBM is a complex process that requires clear attention and focus while planning to evolve such a KB. Thus, for LSS, the critical path was to select appropriate KPIs that lead to having a comprehensive quality assessment process for a sustainable building maintenance context and are able to recommend optimum solutions to environmental issues. The *Designing Stage* is covered by multi-criteria decision-making techniques used to facilitate Lean6-SBM, such as GAP analysis for benchmarking, and AHP for prioritisation. This will be integrated within the process of generating the system's KB rules.

The last stage is the *Implementation Stage* which comes under the operational Level. This stage is divided into two parts: the first one is *Pre-implementation* which evaluates the quick pre-requisites of the LSS implementation; and the second part is *Post-implementation* which is represented in the DMAIC cycle to assess the actual LSS implementation. The implementation strategy in this research is built on extensive investigation of DMAIC key success and failure factors. The framework illustration in Figure 5.5 shows that all of the stages are integrated with a verification, validation, and feedback process. This will accelerate the system development process and enhance the capability of implementing the KB Lean6-SBM in real industries.

These three stages (Planning, Designing, and Implementation) are designed to meet the organisation structure within an SBM environment. The *Planning* and *Designing Stages* are fully integrated under the *Lean6-SBM Level* to assess the readiness of SBM organisations that are interested in implementing LSS, whereas the *Implementation Stage* is designed as a *DMAIC Level* to evaluate completed DMAIC projects in an SBM organisation.

5.3.1 Stage 1: Planning

To achieve the Lean6-SBM conceptual framework illustrated in Figure 5.5, the first step as part of the strategic Level formulates the *Planning Stage*. This stage contains the organisation’s environment, business, and resource perspectives in addition to the change management readiness framework. In this stage, general information on the organisation will be addressed in order to assess strategic capabilities and readiness to change into the new LSS (green) environment. Owing to its criticality, this stage can be described as a filtration chamber that can ascertain whether the organisation can proceed further with LSS implementation or if it will be in need of major improvements.

5.3.1.1 Organisation Business Perspective

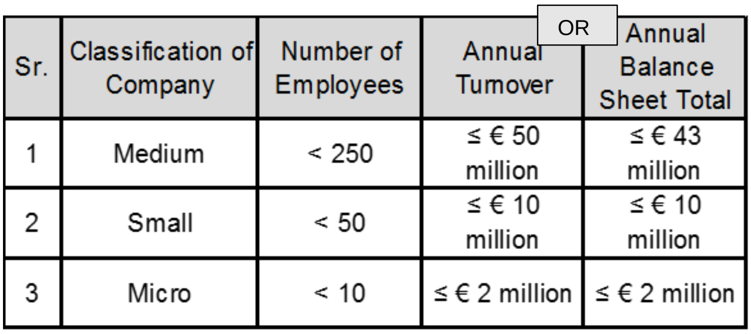
According to Kaplan and Norton (1996), the business life cycle of any organisation can be categorised into three stages: Growth (initial stage usually with negative cash flow and low return), Sustain (expectation of covered return of investment and initial financial goals), and Harvest (establishing new financial goals, focusing on operating cash flow). In this study, these are categorised as less than five years for the Growth stage, 5-15 years for the Sustain stage, and more than 15 years for the Harvest stage. Milana et al. (2014) emphasised that the first component to be identified in any organisation’s environment and business perspectives is the organisational objectives and current state, which should contain general information about the organisation, its financial status, and its market share. These must be analysed and evaluated in order to assess the strength of the organisation in planning the strategy towards implementing Lean6-SBM.

5.3.1.1.1 Organisation Environment

The organisation environment covers the basic strategic statements of the organisation. The organisation statement represents the gate of the organisation's initial identification. It specifies vision, mission, and business objectives that describe the bold guidelines of the business operation. Darbi (2012) concludes that vision and mission are strategic management tools that can affect employee attitudes and behaviours based on empirical studies. These will be developed under the dimension of *Organisation Purpose*.

In addition to this, the organisation's *Strategic Position* will capture the current situation of the SBM organisation, including general information about the age of the organisation, number of employees, suppliers, customers, and number of competitors, which can be used to determine the size of the firm (Nawawi et al., 2008a). Based on Kaplan and Norton (2008), the organisation classification shown in Table 5.1 explains how medium, small, and micro companies (SMEs) are distinguished based on annual turnover and balance sheet (European Commission, 2003).

Table 5. 1 Classification of company based on number of employees and financial statements, adopted from the European Commission (2003)



OR

Sr.	Classification of Company	Number of Employees	Annual Turnover	Annual Balance Sheet Total
1	Medium	< 250	≤ € 50 million	≤ € 43 million
2	Small	< 50	≤ € 10 million	≤ € 10 million
3	Micro	< 10	≤ € 2 million	≤ € 2 million

Logically, it is obvious that large organisations can be classified based on a total number of employees exceeding 250, and annual turnover of more than € 50 million, or annual balance sheet exceeding € 43 million.

The current organisational situation will dig deeper to detect the current capabilities of PM activities. According to Khan and Wibisono (2008), different environments require different performance standards and, therefore, different strategies for improvement. For this reason, the identification stage is essential to ensure the validation of performance diagnosis.

5.3.1.1.2 Financial Analysis

Heads of departments in facility management have to focus on financial indicators along with other performance measures that will reflect the alignment with the organisation strategy (Klammt, 2001). The financial analysis has critical importance in deriving the organisation's actual financial statement, affecting how well it will be able to deliver its KPIs. Based on the main objectives of SBM management, the key financial factors are return on asset (ROA), return on equity (ROE), and return on investment (ROI). These factors will be calculated to assess the organisation's health from a financial perspective (King and Lenox, 2001; Stefan and Paul, 2008). They are basically captured from the financial statements (i.e., balance sheet, income statement, and cash flow statement). According to Joo et al. (2011), the term ROA indicates how efficient the organisation is in using its assets to generate profits, while ROE reveals a percentage of how much profit the organisation achieves with respect to shareholders' investment. Finally, ROI is used to evaluate the investment efficiency. These are going to be determined along with other financial ratios by calculating Leverage Ratio, Liquidity Ratios, and Profitability Ratios to validate the organisation's financial performance in the last three years.

5.3.1.1.3 Market Analysis

In parallel with the financial analysis, market analysis is categorised into market competition and market share. Market competition shows the number of competitors within the same business, whereas market share detects the percentage of business received from the customer base (Mohamed and Khan, 2012).

Market share measures how successful the organisation has been in obtaining market share in its chosen markets. It reflects how competitive the organisation's product or service is in the market and indicates the level of market penetration. This might influence the service lead time that will be managed by LSS. Therefore, it is necessary to analyse the market performance and evaluate how well the organisation is attracting customers or clients through its services.

5.3.1.2 Organisation Resources Perspective

Albliwi et al. (2014) described the lack of resources as one of the main critical failure factors in implementing LSS. Therefore, this stage will identify the organisation’s resources capability that determines technology, financial, and human aspects (Sui-Pheng and Wee, 2001). The functional purpose is to gauge the existing organisation’s capability in terms of the availability of enough resources to carry out the required implementation. As part of the strategic Level, the organisation is needs to prove their readiness to change.

5.3.1.2.1 Human Resource

Human resource development (HRD) is “*a process for developing and unleashing human expertise through organisational development and personnel training and development for the purpose of improving performance”* (Swanson and Holton, 2001: 4). During the assessment process, the system will focus on three core elements within HRD: employee involvement, training, motivation and development planning. The importance of such attributes has been proven in terms of increasing productivity in construction companies (Tabassi et al., 2012), which is relatively close to the BM context. Tabassi et al. (2012) highlighted the importance of individual involvement in organisations and particularly how they affect the knowledge transformation and general strategic objectives. Therefore, the KB rules will seek the percentage of employee participation and involvement. Kaplan and Norton (2008) and Ibrahim and Primiana (2015) have justified the importance and priority of *Human Resource* coaching and development in achieving business excellence. These aspects are going to be derived into *Commitment*, *Programmes*, and *Statistics* dimensions.

5.3.1.2.2 Technology Resource

The second resource pillar is technology, which has been categorised as in *Human Resource* into *Commitment*, *Programmes,* and *Statistics.* Beno et al. (2014) emphasised the power of integrating technology management into the maintenance business process. Again, there must be an evaluation of the degree of involvement in different managerial levels with respect to decision-making in *Technology Resource* development (Tabassi et al., 2012). This leads to look further into assessing the tools that promote employees' participation (e.g., suggestions, ideas) and the difficulties behind implementing them (Neagoe and Klein, 2009). On the other hand, there is a need to investigate the workshops environment and physical layout as they have extreme implications for the workforce and hence, the overall productivity (Chandrasekar, 2011).

5.3.1.2.3 Financial Resource

The third investigation area in measuring organisational resources capabilities is the *Financial Resource*. Mohd-Noor et al. (2011) have declared that budget allocation in building maintenance can be categorised into three main elements: budget allocation for employees, technology, and implementation. One of the critical success factors in implementing a programme of change in any organisation is measuring financial commitments capability, as well as organisation culture, organisational readiness, managerial commitment, adequate resources, and clear communication (Radnor and Bucci, 2007). Therefore, it is quite important to evaluate the current performance of organisational financial resource. From that perspective, this study is triggering the budget allocated for *Employees, Technology*, and *Implementation* that is necessary to execute PM activities.

5.3.1.3 LSS Readiness for Change

It is obvious from the literature review that more than 90% of the surveys conducted in Lean, Six Sigma, and LSS projects (Laureani and Antony, 2011; Goh, 2012; Albliwi et al., 2014) revealed that resistance to change and management commitment are the main impediments against successful project implementation. Despite the built-in change management awareness process in the DMAIC model, there is a need for an out-of-the-box comprehensive plan to assess and analyse the readiness to change in order to tackle such obstacles. Gerbec (2016) highlighted the essentiality of integrating organisational changes and technology aspects, involvement of different managerial levels in decision-making, and ensuring proper continuity of communication between stakeholders. Thus, the SBM organisation's readiness will be tested prior to LSS implementation to highlight the degree of gap points. The readiness test framework in this study has been developed based on previous change management frameworks conducted by the Bryan (2008) and Gerbec (2016). These frameworks have been analysed and verified to enhance the LSS change management approach within three main aspects: ICT, Share Values, and Soft TQM which have been selected based on that review.

5.3.1.3.1 Information and Communications Technology (ICT)

The rapid increase in market competition forces organisations to continuously improve their product/service quality in order to stay in the market. Campos (2009) described that one of the critical measures usually taken by manufacturing organisations is to reduce the operations and maintenance cost by cutting the cost of condition based maintenance. This practice is very risky if the organisation has not built an integrated system that can assist in monitoring various assets. According to the ICT Authority (2014), information and communications technology (ICT) is storing, retrieving, transmitting and receiving of electronic data in addition to supporting the communication between these departmental levels through a valid integration. Therefore, the ICT masterplan is a roadmap to an economic spread of knowledge where it creates challenges for the ICT department in fulfilling the continuing development of learning of the organisation (Sunindyo et al., 2013). Ritchie and Brindley (2005) have proved the significance of ICTs as drivers of change from case studies, and significantly influencing all dimensions of business, both internally and externally. Patterson et al. (2009) have determined how ICT contributes energy-saving measures if it is efficiently integrated into facilities management. Furthermore, Alkazemi (2014) has identified four assessment criteria to evaluate the efficiency of legacy systems - used in organisations - these are: effectiveness of service level agreement (SLA), fulfilment of business requirement, effectiveness of system architecture, and effectiveness of system technology.

5.3.1.3.2 Share Values

According to Amah and Ahiauzu (2014), organisational values are important since they form a challenge to the organisation management. LSS project managers are seeking ways to coordinate and integrate people with diverse personality and cultural value systems. Share values can be described as beliefs, values, and expectations that can be held consensually by members of an organisation. According to Buthmann and Kaufmann (2015), a LSS project manager has to achieve a certain level of leadership competencies as follows: 25% of functional know-how, 25% of business knowledge, 25% of process improvement, design and management know-how, and 25% of change leadership ability. In addition, coordination and integration (*Cross-functional Collaboration*) enable different functions and departments to achieve common goals of organisational values by communicating and working together (Amah and Ahiauzu, 2014). Over and above that, Amoako-Gyampah and Salam (2004) highlighted the importance of homogeneity in employees, *Shared Beliefs,* and how it affects overall organisation benefits. They cited that Dr Parsons, a Harvard sociologist, has insisted on the importance of *Share Values* in which it explores the degree of social relations that affect organisational performance systems (Parsons, 1979).

5.3.1.3.3 Soft TQM

In order to implement change, managers must take into account three main strategies, which include: active participation, persuasive communication, and management of information (Armenakis and Harris, 2002). According to Saleem et al. (2012), TQM is classified into the soft part, which deals with human involvement and commitment, and the hard part, which is the representation of tools and techniques used to develop quality improvement. Oakland (2014) described that people are the key element of activating the soft TQM. Therefore, organisational performance cannot be achieved without strengthening the interrelationships among all TQM soft elements, which include *Commitment, Communication* and *Culture* working together. Rahman and Bullock (2005) proved that the strongest relationship between soft TQM and organisational performance represents the pivotal part within the hard elements. In fact, the soft elements in high performance organisations are always working together. According to Chandrasekar (2011) a documented communication system between employees in the workplace can promote their trust and build up relationships (*Culture*) within a strong team. He highlighted the significance of superiors in facilitating (*Commitment)* the resources required to complete satisfactory work orders.

5.3.2 Stage 2: Designing

The *Designing Stage* is identified as the second stage. It will study the core business of the organisation by assessing the capability of integrating LSS to support relevant know-how of SBM based on the applied taxonomy structure described in Chapter 2 (Section 2.6). In this stage, the KB Lean6-SBM model will proceed with benchmarking and prioritisation by integrating GAP and AHP techniques, respectively. The outcome of this stage will reflect how far the organisation or maintenance department is from the desired best practice (benchmark).

5.3.2.1 LSS Sustainable Building Maintenance Perspective

According to Lind and Muyingo (2012), BM strategies can be divided into two types: corrective (e.g. planned and immediate) maintenance, which can be applied after detecting a fault, and preventive maintenance (PM), which is applied before detecting the fault. PM is categorised into immediate opportunistic and planned, in which the maintenance is performed according to the manufacturer's recommendations (e.g. condition-based, time-based, planned opportunistic, and predictive). The reprinted pictorial shown in Figure 2.3 illustrates the BM strategies.

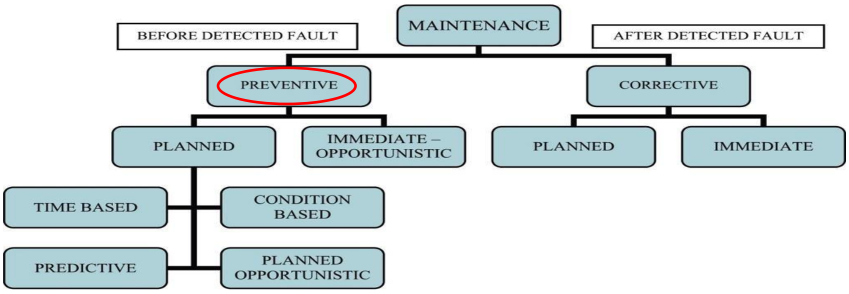


Figure 2.3 Building maintenance strategies, adopted from Lind and Muyingo (2012) (Reprinted from Chapter 2)

It has been mentioned previously that this research will focus on PM, utilising the BM taxonomy driven by Motawa and Almarshad (2013), which comprises three main aspects: the *Legal* aspect, which evaluates contractual attributes, environmental, social, and economics issues; the *Technical* aspect, which refers to the *Work Orders* planning, scheduling, executing, and quality control; the *Administrative* aspect, in which it assures the support of operation management.

5.3.2.1.1 Legal

Yahya and Ibrahim (2011), Omar et al. (2013), and Hon et al. (2014) have described the essentiality of assessing a building maintenance organisation in terms of how it is committed to the maintenance contract conditions, building regulations, health, and safety. Efficient maintenance organisation requires contracts with clear segregation, well-defined scope, specification, and statutory requirements, as well as effective coordination between different departments (Lai et al., 2006). This stage has been designed to incubate the contractual main critical and ambiguous attributes along with the environmental sustainability aspects within a sustainable building maintenance taxonomy. It is essential to have standard forms of contract which might cover some common contract conditions of building maintenance. The degree of practitioners' preparation and adaptation may gain substantial savings amongst different contracts where the standard forms are suitable (Lai et al., 2006). Manufacturing today consumes a significant amount of energy and water to produce the items consumers demand. These resources, to minimise the impact of their consumption on the environment, need to be used as efficiently and effectively as possible (Robinson, 2013). With regards to social metrics, safety policies and legislation can drive down the accident rate very effectively to an acceptable level, however, continuation with safety improvements can only be achieved by applying a positive safety culture (Hon et al., 2014). For an economic perspective, a contribution of the company towards corporate social responsibility (CSR) has to be evaluated. The study by Jones et al. (2006) revealed the importance of supply chain management and communities as critical CSR aspects in the UK contraction firms that will lead to improvement of future economics.

5.3.2.1.2 Technical

Based on the building maintenance taxonomy introduced by Motawa and Almarshad (2013), the technical work package represents the crucial aspect as it contains the main elements which form various building functional systems. This stage has been designed to evaluate the organisation’s technical performance ability in managing maintenance work orders’ backlog by evaluating the business processes related to planning, scheduling, executing, and quality control. These have been declared as the essential KPIs in a work order’s lifecycle (Mobley, 1991; Mobley and Smith, 2011). They described planning as the heart of preventive maintenance in which it takes the responsibility of estimating time, labour cost, and materials. In addition, he claims that scheduling bears more relation to demand and supply balancing. The demand depends on equipment’s need for preventive maintenance whereas supply is concerned with the availability of the workforce, spare parts, and the equipment itself to carry out the required task. Both planning and scheduling represent the backbone of PM activities that must be evaluated to determine their efficiency within the organisation’s capabilities. On the other hand, and according to Mobley and Smith (2011), the world-class level of quality in work order execution (maintenance rework) is less than 3% which could increase dramatically if there is a lack of follow-up. Thus, it becomes crucial to investigate the work order execution and quality control in the *Technical* aspect of the BM taxonomy.

5.3.2.1.3 Administrative

Jardine and Tsang (2013) declared that in order to reach high maintenance efficiency and productivity, a reasonable investment in new assets and maintenance costs within budget must be achieved. Based on the building maintenance taxonomy introduced by Motawa and Almarshad (2013), the *Administrative* part signifies the third aspect of the SBM module which focuses on budget compliance. In order for the organisation to be fulfilled with the target budget compliance, the total cost of preventive maintenance workforce personnel, their training, materials used, as well as any other related costs have to be calculated and compared with the total maintenance cost. The target of operations budget compliance is set at 15%-18% based on British Standards (BSI, 2007).

5.3.3 Stage 3: Implementation

It has been declared that the *Implementation Stage* in this research is built on having a *Pre-implementation* phase as a screen-type approach before processing further with the DMAIC rigid structure technique. However, the idea of this stage is to evaluate those organisations that have already experienced a real LSS implementation.

5.3.3.1 DMAIC Implementation

From previous researches, the use of the DMAIC cycle as an LSS methodology in the SBM environment has been justified (Michael Ruiz et al., 2013; Youssouf et al., 2014; Michael Whittaker, 2016). Mast and Lokkerbol (2012) described the structure of Six Sigma under the acronym DMAIC as an effective quality management procedure. It relates to continuous improvement and stands for Define, Measure, Analyse, Improve, and Control. However, for the sake of DMAIC project preparation, the KB Lean6-SBM has embedded a *Pre-implementation* stage to assess the awareness and fulfilment of the prerequisites.

5.3.3.1.1 Pre-implementation

As explored in Chapter 3, failing in transforming into an LSS culture is mostly caused by lack of commitment and training in addition to other critical aspects like project selection, lack of resources, and poor communication, as determined by Albliwi et al. (2014). According to e-Careers-Limited (2013), clarity, data, and benefits are essential for project selection. The problem must be documented and clear to all governance, the historical data, which might be needed, must be available, and finally there must be a worthy benefit to start up the required project.

Thus, in order for this stage to determine how far the organisation is from fulfilling the DMAIC project requirements, the assessment will be categorised into four sections: *Benchmark* (with other organisations' standards), *Assessment* (of LSS project team in their familiarity with DMAIC cycle phases), *Measurement* (project selection, availability, clarity, and accuracy of data history), and *Action* (ability to use essential LSS tools/techniques to capture customer needs and employees' responses*)*. These are essential to identify weaknesses and opportunities with respect to LSS before implanting any DMAIC project in an SBM context.

5.3.3.1.2 Post-implementation

This stage elaborates on the DMAIC cycle as an implementation process. The evaluation has taken place for ongoing and executed DMAIC projects. The project team must *Define* some parameters in conjunction with their sponsors. They should specify the problem, stakeholders, how customers are affected, and why the current process fails to satisfy their needs. Moreover, they should agree on the project boundaries and the indicators used to evaluate the success (George et al., 2003). According to Mast and Lokkerbol (2012), the problem is translated into a measurable form (*Measure* phase). The current situation is measured, and the objectives should be redefined. The business process must be described, and the variations must be quantified. In the *Analysis* phase, potential factors that influence the quality practice are identified. The purpose is to utilise data and information collected in the *Measure* phase to confirm the sources of waste, delays, and poor quality (George et al., 2003).

In the area of *Improve*ment, a pilot test must be conducted, and improved solutions are to be identified, verified, validated, tested, and deployed (Ramanan et al., 2014). The cycle will be closed with a *Control* and monitoring phase that must be initiated. George et al. (2003) stated that the main aim of the *Control* phase is to preserve any gains made until evidence of a better method must be addressed. The team must be re-assured that every project member is well trained. Any improvement in the process must be documented, and the results are to be reflected by the amount of money gained. Visual KPI screens must be installed and monitored to assist in continuous process improvement.

5.4 Structure of KB Lean6-SBM

By achieving the second objective of this research through the creation of the KB Lean6-SBM model, followed by the conceptual framework, the next step is to convert it into a structured model. This type of hierarchical Level will enable the development of the required KBS, starting with the most strategic Level, and ending with the most operational Level.

The system is designed structurally as illustrated in Figure 5.6 to have an effective decision-making process and hence a strong correlation must exist within all the organisation's departments. Thus, it is a clearer interpretation of how the KB Lean6-SBM will be developed. The framework has been developed based on a standard managerial organisation structure. Therefore, the proposed conceptual design structure has taken into account the hierarchy of decision-making which will vary between strategic and operational Levels.

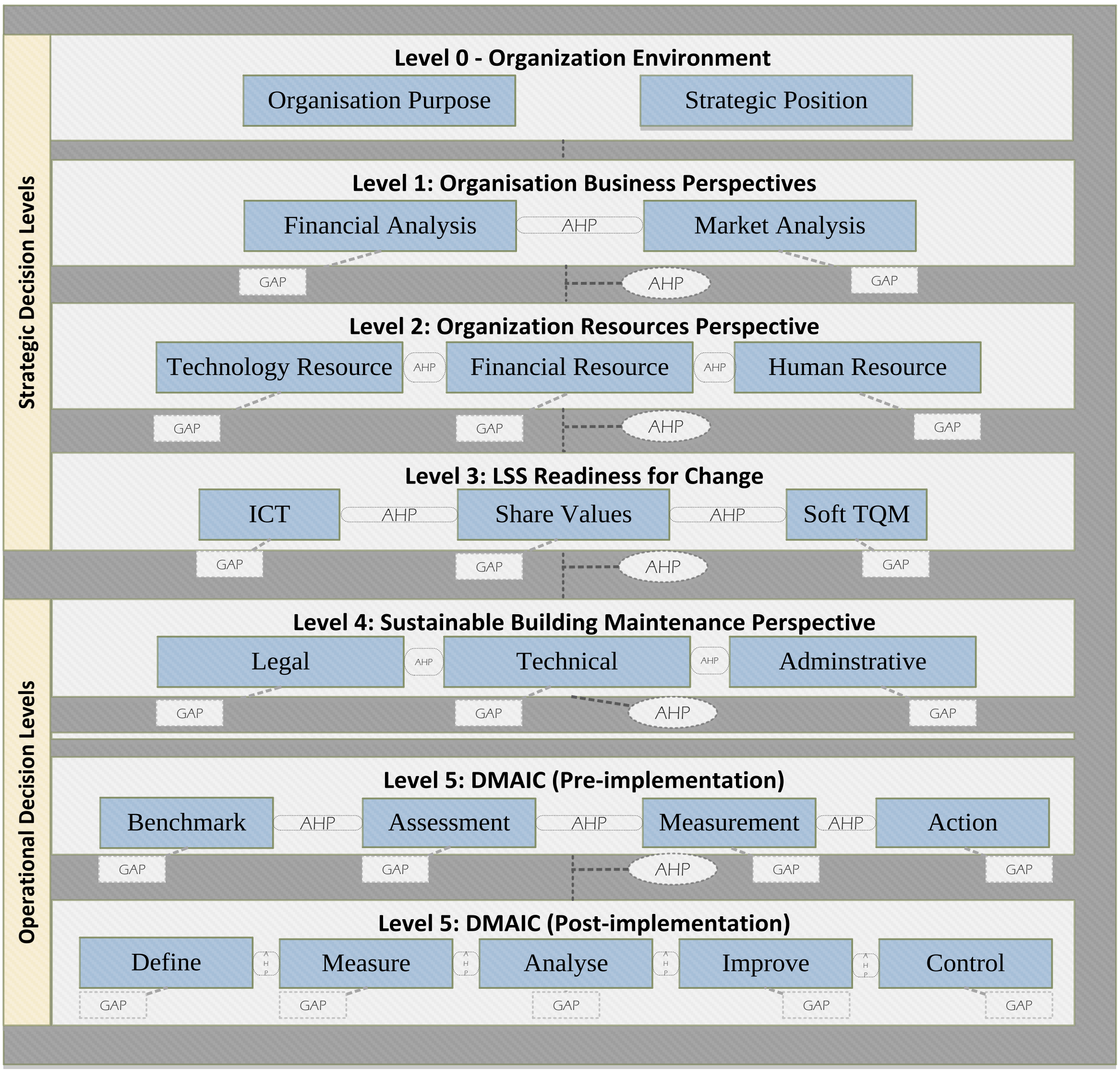


Figure 5. 6 Structure of KB Lean6-SBM System

As seen in Figure 5.6, the strategic issues fall under structure *Levels 0-3*, whereas the tactical and operational issues are under *Levels 4 and 5*. It is obvious that there is only one pre-requisite (*Level 0*) and four perspectives (*Level 1-Level 4*) of the organisational performance criteria in the KB Lean6-SBM. Generally, the structural model represents the interrelation among all Levels (*Level 0-Level 4*) and the areas in which to perform GAP analysis and AHP prioritisation improvement techniques. For Level 5, the pre-requisite and interrelation are built in between two stages (i.e. *Pre-implementation* and *Post-implementation*).

5.4.1 Hybrid KB/GAP/AHP Lean6-SBM System

A KB System is one of the AI concepts and methodologies. According to Khan et al. (2011), this kind of system acts as an intelligent tool which in most cases should replace expertise in certain areas. As cited in Chapter 4, KB Systems are extensively used in many applications such as engineering, medicine, and banking. This gives an obvious indication of how powerful and reliable these systems are to ensure consistency in dealing with rapid decision-making.

Based on the research objectives discussed in Chapter 1, this study intends to design and develop a hybrid KB-AHP-GAP rule-based system that integrates LSS with preventive maintenance (PM) in sustainable building environments. The approach of a KBS with GAP and AHP will enhance the design and development of Lean6-SBM, which has not been performed in the past. In this respect, GAP will facilitate the benchmarking of the current organisation’s state with the desired one, whereas AHP will be used to prioritise the recommended solutions based on GAP analysis and weightage criteria.

Depending on the content and context, the answer options for any question in the KB System are given during the interviews. It might be a closed answer (in which the options of the correct answer are given in a range of intensity or relevant practice) or an open answer (in which the user must provide his personal experience or comments in that particular practice). However, the closed answer is considered to be the best with which to provide the correct input into the Lean6-SBM model. The importance of the answering statement will be scaled by problem category (PC) in case the question is intended for GAP analysis. As mentioned in Chapter 4 (Section 4.10), the scales will be in the range from PC-1 to PC-5 where PC-1 has the higher (importance) weightage scale.

Some questions might be confusing or difficult to understand (i.e. fuzzy/uncertain), therefore, the explanation facility is used to avoid any misunderstanding by the user of the question given. This contains additional information and knowledge about key areas such as standardised definitions or statements that will help the user understand the question. According to Nawawi et al. (2008b), this facility might be utilised to promote industrial recommended best practices. Thus, it will be used for the Lean6-SBM model instead of using Bayesian probabilities or fuzzy logic to detect and eliminate any uncertainty in understanding the KB rules.

5.4.1.1 Application Manager (AM)

This research will extend the use of the ES shell known by *AM Builder*, which has built a reputation as a powerful tool from previous studies (Nawawi, 2009; Huai, 2012). It will be used to develop the KB Lean6-SBM. This application is designed by Intelligent Environments Inc., and as stated by Mohamed (2012), AM allows users to develop an effective standalone system in a short time with a highly interactive user interface. It uses the production rules technique to represent knowledge that will be activated through AM objects. These objects are module, procedures, commands, windows, menus, functions, and variables. By using these objects, KB Lean6-SBM will be developed in a logical format with the ability to store and retrieve data based on the rules produced.

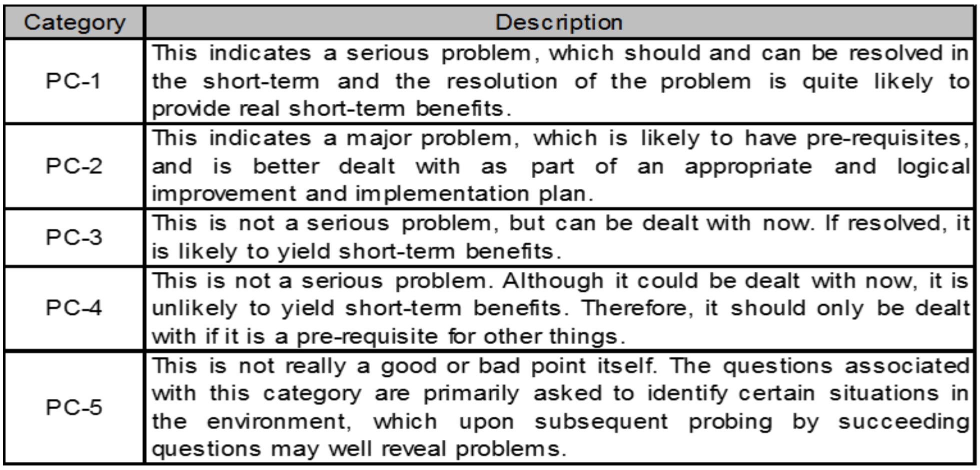
The KB Lean6-SBM application is normally designed with a built-in *Display* windows tool that acts as a user interface in which the communication is driven between the system and the user. As a user-friendly interface feature, there will be a provision to display any question, answer options, and the explanation facility in one screen.

5.4.1.2 GAP for Lean6-SBM

GAP will incorporate the design model with the benchmarking process. According to Williams (2008), benchmarking is divided into internal benchmarking and external benchmarking. The British Quality Foundation (BQF) has classified the same into strategic, performance, process, functional, internal, external, and international benchmarking. Despite all of these types, this research will focus on internal and external benchmarking. The BQF (2015) describes internal benchmarking in terms of comparison to the standard of business and operations within an organisation, whereas external benchmarking analyses the best practices outside the organisation by learning from the leading edge.

The information needed to apply GAP is collected from the users through the designed questionnaire embedded in the KB Lean6-SBM System. Achievement of the required standard performance will be scored by good points (GPs), and the points that refer to identified problems will be scored by bad points (BPs). These problems are categorised with respect to the severity and tagged with PC as illustrated previously in Table 4.5.

Table 4.5 Problem Categories (PCs) of GAP analysis (Reprinted from Chapter 4)



Category	Description
PC-1	This indicates a serious problem, which should and can be resolved in the short-term and the resolution of the problem is quite likely to provide real short-term benefits.
PC-2	This indicates a major problem, which is likely to have pre-requisites, and is better dealt with as part of an appropriate and logical improvement and implementation plan.
PC-3	This is not a serious problem, but can be dealt with now. If resolved, it is likely to yield short-term benefits.
PC-4	This is not a serious problem. Although it could be dealt with now, it is unlikely to yield short-term benefits. Therefore, it should only be dealt with if it is a pre-requisite for other things.
PC-5	This is not really a good or bad point itself. The questions associated with this category are primarily asked to identify certain situations in the environment, which upon subsequent probing by succeeding questions may well reveal problems.

5.4.1.3 AHP for Lean6-SBM

AHP is a powerful technique which can sustain both qualitative and quantitative criteria. Therefore, it has been chosen to be integrated with Lean6-

SBM through element linkage and the priority weighting approach. During the operation of the KB Lean6-SBM System, and based on Saaty (2008) AHP approach, the comparisons between the elements are made using an absolute judgement scale which will show how much an element dominates another based on given attributes. Saaty insists that weighting the priorities of the alternatives in order to obtain the required rank is a challenging task, however, AHP can deal with such a challenge.

In order to achieve effective implementation of AHP in KB Lean6-SBM, the following section describes the procedures that will be followed based on the method description stated in Chapter 4 (Section 4.11).

5.4.1.4 The Hybrid System for Lean6-SBM

The problem to be solved in this research, with the support of AHP, is to decide the priorities of improvements in Lean6-SBM. The KB Lean6-SBM System will be contributed to by business, resources, LSS readiness for change, and SBM perspectives. Thus, the decision hierarchy for Lean6-SBM is structured so that the goal is on top, followed by the specified criteria on the next Levels as shown in Figure 5.7.

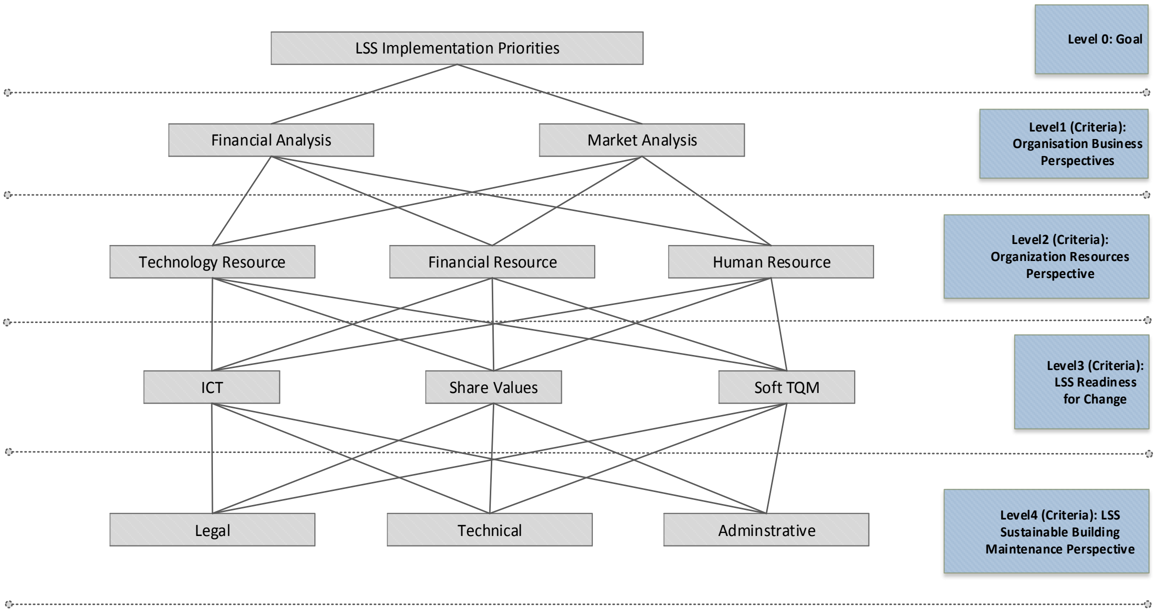


Figure 5. 7 AHP Structure for KB Lean-6SBM

The hierarchy illustrated above starts with *Level 0,* which formulates the goal to be achieved through AHP in KB Lean6-SBM. The next Levels demonstrate the criteria used to achieve that goal. In *Level 1, Business Perspective*, there are two sub-criteria identified: financial analysis, and market analysis. They are linked to the sub-criteria in *Level 2, Resources Perspective*. These are *Human Resource*, *Technology Resource*, and *Financial Resource*. Again, the upper Level influences the next sub-criteria, which belong to *LSS Readiness for Change* in *Level 3*. This Level has three sub-criteria: *ICT*, *Shared Values*, and *Soft TQM*. In fact, they will affect the criteria of SBM, which comes next in *Level 4.*

The hybrid KB/GAP/AHP integrates both GAP and AHP in a KB System. The GAP analysis in this research is obtained from the user/participant response to the questions designed in the System. The algorithm starts with the weight assigned to the five PCs using the AHP pairwise comparison technique. The five-point scales of PCs are then structured in a form of matrix as shown in Table 5.2, considering PC-1 more important than PC5 in terms of problem identification. Therefore, the comparison logic in this regard is PC-1>PC-2>PC-3>PC-4>PC-5.

Table 5. 2 The Five-Point Scale (PCs) Matrix

	PC-1	**PC-2**	**PC-3**	**PC-4**	**PC-5**
PC-1	1	2	3	4	5
PC-2	1/2	1	3/2	4/2	5/2
PC-3	1/3	2/3	1	4/3	5/3
PC-4	1/4	2/4	3/4	1	5/4
PC-5	1/5	2/5	3/5	4/5	1

Kochhar et al. (1991) described the weighting value based on the Problem Categories on a qualitative value judgment that a severe Problem Category (PC-1) is valued at 5, a major problem PC-2 at 2.5 and there on. The current researcher agrees with this judgment. Each PC is calculated by dividing the highest value of PCs by each corresponding PC. In this case, the highest value is 5 dividing it by 1 for PC-1 gives 5 which means PC-1 is five times more important than PC-5. Then, dividing 5 by 2 gives 2.5 which means PC-2 is 2.5 times more important than PC-5. The same process continues for the rest as summarised in Table 5.3.

Table 5. 3 Weightage Summary of Problem Categories

Problem Category	PC-1	PC-2	PC-3	PC-4	PC-5
Weight	5/1 =5	5/2 =2.5	5/3 =1.67	5/4 =1.25	5/5 =1

Combining GAP analysis and the AHP technique, specific algorithms are required to be created in order to match between the five scales' degrees (PCs) of

GAP and the nine scales' degrees of AHP intensity. This is done by transferring the five-point scales of GAP into AHP intensity point-scales (Nawawi, 2009). Based on the assumption that a component (A) belongs to PC-1 (least point) and having 100% of the points and a component (B) belongs to PC-5 (highest point) and having 100% of points, the process starts by determining the difference between both of the components. The difference is multiplied by the weight of the PC to determine the performance score (PS). Finally, the total PS for all the PCs is determined and the value is equal to 400 points as shown in Table 5.4.

Table 5. 4 Performance Scores (PS) of PCs

PC	Weight	A (%)	B (%)	A - B	PS = (A-B)* weight
1	5	100	0	100	500
2	2.5	0	0	0	0
3	1.67	0	0	0	0
4	1.25	0	0	0	0
5	1	0	100	-100	-100
Total		**100**	**100**		**400**

Based on AHP's nine scales of intensity, the interval between each point can be identified by dividing the total PS (400) by the number of intervals in the intensity scale (8) which gives 50. This means that the lower PS in GAP is 0 with the lowest intensity scale, and the higher PS is 400 with the highest intensity scale of 9; these can be summarised in Table 5.5 as the guide of PSs after combining GAP and AHP.

Table 5. 5 The Guide of Transfer GAP into AHP

AHP importance Intensity	Priority Comparison for Improvements (A to B)	PS
1	Equal importance	PS = 0
2	Very weak importance	0 < PS ≤ 50
3	Weak importance	50 < PS ≤ 100
4	Moderate importance	100 < PS ≤ 150
5	Importance	150 < PS ≤ 200
6	Strong importance	200 < PS ≤ 250
7	Very strong importance	250 < PS ≤ 300
8	Almost absolute importance	300 < PS ≤ 350
9	Absolute importance	350 < PS ≤ 400

Based on preference matrices, priorities are obtained at each Level of criteria and sub-criteria. As described in Chapter 4, the importance of intensity must be assigned for each component, which leads to the need for maintaining a consistent matrix as stated by Saaty and Vargas (2012). They emphasised that AHP will help determine this consistency based on calculating the consistency ratio (CR). The CR should be less than or equal to 10%, otherwise, there will be inconsistency in the matrix, and hence the subjective judgement must be revised. The CR can be calculated by the equation below:

$CR = \frac{CI}{RI}$, where CI is the Consistency Index (degree of consistency) and RI is the Random Consistency Index, which is normally known. The Consistency Index is calculated by: $= \frac{\lambda \max - n}{n-1}$, where n is the size of the comparison matrix and λmax is the largest eigenvalue in the matrix (Saaty and Vargas, 2012). The example of performing the mathematical calculation for AHP process is explained in Appendix A.

Thus, based on the above analysis, after assigning intensity of importance for each aspect in the form of matrices, a normalisation process takes place to determine the priority weights for each matrix. The result is validated through calculating the CR for each matrix. If the CR is less than or equal to 0.10, it confirms that the pairwise comparison is consistent. Otherwise, the decision maker has to review the comparison again.

5.5 Summary

In order to produce an effective KB Lean6-SBM System, this chapter has described the main practical steps representing strategic and operational phases. It starts by producing a KB Lean6-SBM model which has been verified consistently. The next stage in the development is done by converting the model into a conceptual framework and then into a structural hierarchy format.

The model demonstrates the *Planning Stage* in the strategic phase, in which the organisation's business statement is identified and resources and readiness to change are assessed. The next phase in the model is the *Designing Stage*, which incorporates the main pillars of this research (i.e. LSS and SBM perspectives) that deals with the aspects of LSS and how they integrate with sustainability metrics in the maintenance environment. The implementation phase comes last to represent the operational side with two stages: *Pre-implementation* and *Post-implementation*.

This chapter has elaborated in detail the key aspects in each Level of the framework and the essentiality of having such factors with evidence from the literature review. Based on their Levels, these aspects are *Level 0: Environmental*; *Level 1: Financial Analysis* and *Market Analysis*; *Level 2: Human Resource*, *Technology Resource*, and *Financial Resource; Level 3: ICT, Shared Values*, and *Soft TQM; Level 4: Legal, Technical,* and *Administrative; Level 5: DMAIC Implementation* (*Pre-implementation* and *Post-implementation*).

The hybrid integration of GAP analysis and AHP methodology has been discussed with a focus on identifying the weightage of problem categories (PCs) and the degree of importance through further GAP to AHP scoring transfer process. Also, the chapter has highlighted an example of the AHP calculation process using the research data.

This chapter contributes the conceptual framework of the research, which is used to derive the KPI elements and process flow charts that act as a roadmap to generate the desired KB rules. Subsequently, this will lead to a comprehensive hybrid KBS that will be supported by benchmarking (GAP) and prioritisation (AHP) improvement techniques.

The following chapter will present a thorough development of the KB Lean Six Sigma Maintenance System for Sustainable Buildings (Lean6-SBM) model that explores the *Planning, Designing, and Implementation* Stages in detail.

CHAPTER 6

Design and Development of Knowledge-Based Lean Six Sigma Maintenance System (KB Lean6-SBM)

6.1 Introduction

This chapter focuses on a comprehensive development of the KB Lean6-SBM model. It elaborates on all Levels in the structure of the KB Lean6-SBM system for the three stages as described and reprinted from Chapter 5. This involves acquiring the knowledge rules and related knowledge structure for each module of the system (demonstrating the process of knowledge acquisition by the *Knowledge Engineer*). The development of flow charts and KB rules are based on a literature review, extensive review with research supervisors, industry experts, standards, publications, feedback, etc. These rules are reformatted into structured questions, with which it becomes easy for the user (participant) to interact.

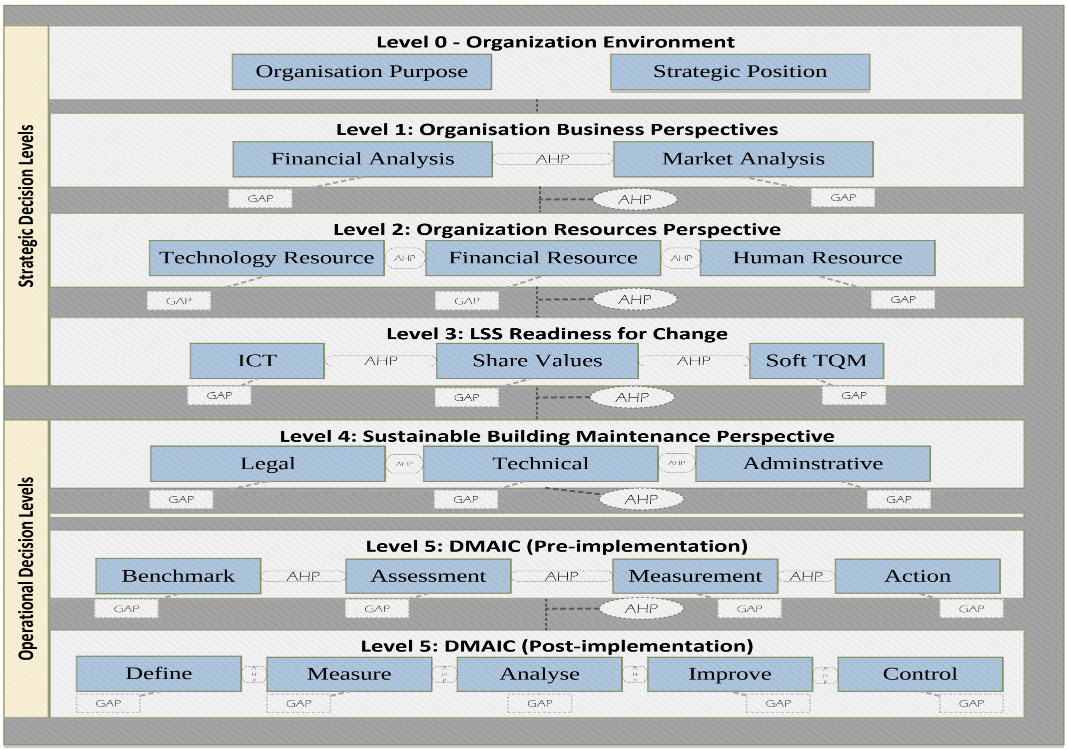


Figure 5.6 Structure of KB Lean6-SBM System (Reprinted from Chapter 5)

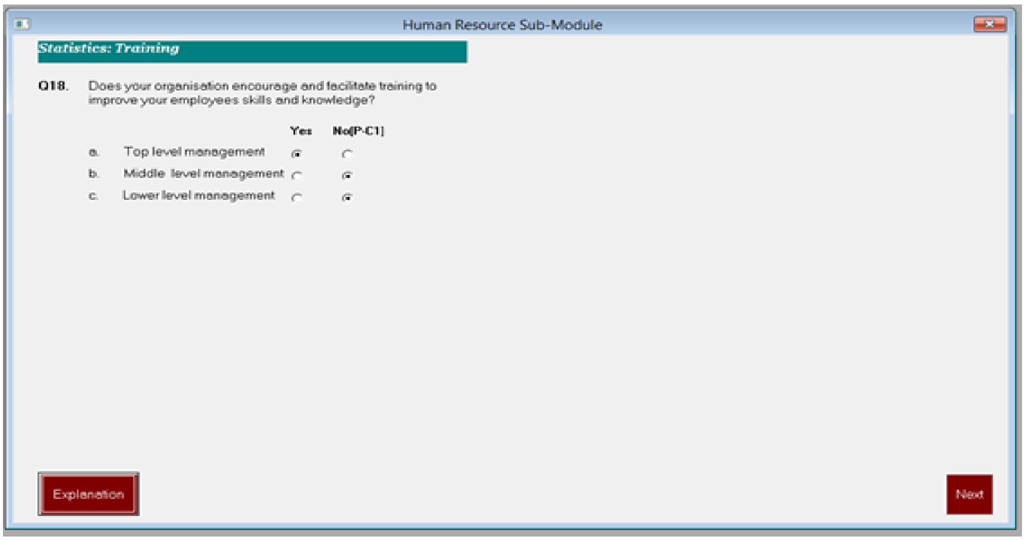
These questions are designed to capture both qualitative and quantitative information for the current situation across all Levels bearing in mind the identification of GAP analysis in each aspect. This is followed by applying the AHP technique to determine which aspect has priority over the others in order to achieve the KB Lean6-SBM benchmark standard.

The system provides the facility of explanation for some rules that are ambiguous or difficult for the user to understand. In fact, it contains guidelines and referenced quotes which describe the importance of that specific rule in a particular environment. This will help in giving confident answers that will lead to a realistic solution.

For the complete KB Lean6-SBM system (Level 0–Level 5), over 2,500 KB rules have been developed and structured. For demonstration purposes, and due to the large number of KB rules involved, the discussion of each module will be followed by key rules only. The following KB rules set illustrates a generic example of a typical rule-based structure in Lean6-SBM:

```
IF  Your organisation top level management encourages and facilitates training to improve your employees skills and knowledge (Yes: GP; No: BP-PC-1)
AND The trend of training hours facilitated by top level management has increased continuously in the last three years (Yes: GP; No: BP-PC-2)
THEN    Your organisation has a good training investment based on top level management involvement
ELSE IF Your organisation middle level management encourages and facilitates training to improve your employees skills and knowledge (Yes: GP; No: BP-PC-1)
AND The trend of training hours by middle level management has increased continuously in the last three years (Yes: GP; No: BP-PC-2)
THEN   Your organisation has a good training investment based on middle level management involvement
ELSE IF  Your organisation lower level management encourages and facilitates training to improve your employees skills and knowledge (Yes: GP; No: BP-PC-1)
AND    The trend of training hours by lower level management has increased continuously in the last three years (Yes: GP; No: BP-PC-2)
THEN Your organisation has a good training investment based on lower level management involvement
ELSE    Your organisation has to focus on investing adequate training programmes at all managerial levels
ENDIF
```

The above KB rules are reformatted into questions as shown in Figure 6.1. It is very important for the questions to be clearly defined in a logical order. The KB rules are fired based on user response for a particular question and related subsequent questions. Another key aspect in KB Lean6-SBM is the accurate categorisation (*Problem Category*) of each rule which has been determined through literature review and discussion with supervisors and industry experts.



Statistics: Training

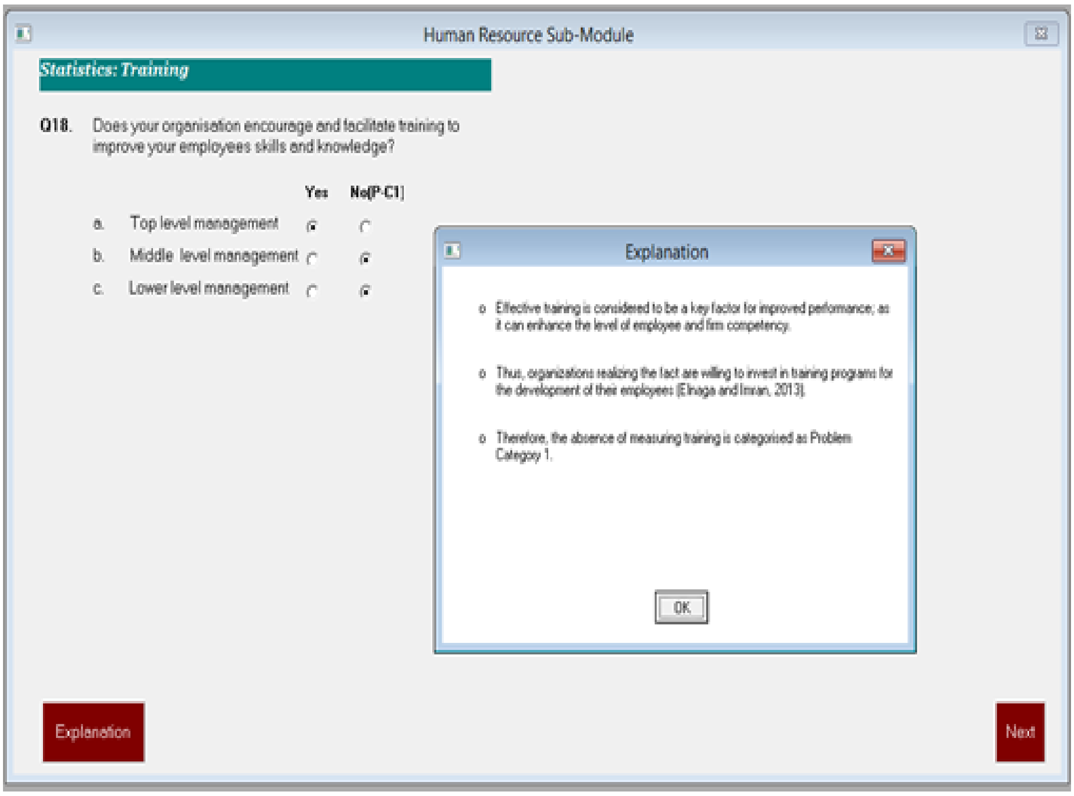
Q18. Does your organisation encourage and facilitate training to improve your employees skills and knowledge?

		Yes	No[P-C1]
a.	Top level management	●	○
b.	Middle level management	○	●
c.	Lower level management	○	●

Figure 6. 1 Generic Example of KB Rules Questions

Figure 6.1 shows a print screen for part of the reformatted questions which relate to the Human Resource sub-module for the Lean6-SBM environment. It starts by asking the user if the top, middle, and lower levels' management are facilitating training to improve the employees' skills and knowledge. If the answer is 'No' for any of the sub-category, then it signifies a serious gap in the current environment that will be counted as a critical aspect in the KB Lean6-SBM. If the answer is 'Yes', the system will execute another question which seeks the number of training hours for that sub-category in the last three years. If the trend of the training hours is continuously increased, the system will count it as a Good Point (GP), otherwise, it will be counted as a serious problem with *Problem Category* (PC-2).

As mentioned in Chapter 5, the current research has not used Bayesian probabilities or fuzzy logic to clarify uncertainty of understanding the KB questions. Thus, to overcome fuzziness and ambiguity in understanding the KB questions, the KB Lean6-SBM model utilises the *Explanation* facility which is illustrated in Figure 6.2 as a typical example exploring the questions in Figure 6.1.



Statistics: Training

Q18. Does your organisation encourage and facilitate training to improve your employees skills and knowledge?

	Yes	No[P-C1]
a. Top level management	●	○
b. Middle level management	○	●
c. Lower level management	○	●

- Effective training is considered to be a key factor for improved performance; as it can enhance the level of employee and firm competency.
- Thus, organizations realizing the fact are willing to invest in training programs for the development of their employees (Elnaga and Imran, 2013).
- Therefore, the absence of measuring training is categorised as Problem Category 1.

Figure 6. 2 A Typical Example of Explanation Facility

The *Explanation* box includes additional information to help the user to choose the right answers. Despite the awareness of being explicit in each question, some terms may misguide the user and hence their understanding which will ultimately lead to wrong answers and consequently invalid recommendations. The following sections will discuss in detail the interrelated aspects for each Level within the KB Lean6-SBM System. However, in order for the next step to be represented successfully, the IDEF0 functional modelling method will be used. In fact, IDEF0 is widely known because it models actions, activities, and decisions among different Levels to facilitate smooth, functional communication. In other words, it is a precise way to model real-world operations because it enables communication among technical and non-technical enterprise staff (Feldmann, 2013). Therefore, it is the best way to further develop the structural design into most of the Lean6-SBM functional requirements. The representation of the IDEF0 will be followed by designing the system flow charts and producing the KB rules. The knowledge used to develop the flow charts and the KB rules is captured through literature review, related books, supervisors, and industry experts.

6.2 Level 0: Organisation Environment

The *Organisation Environment* is the first module that needs to be investigated. It compiles general information and background of the organisation. The *Organisation Environment* Level helps to capture data about the environment of the organisation and its performance. The rules embedded in the module will establish relationships, converting that data into information. By assessing or comparing the level of performance of the organisation, the module will convert that information into recommendations about strategic issues of the organisation (knowledge or know-how). This Level can be illustrated in the IDEF0 model diagram shown in Figure 6.3.

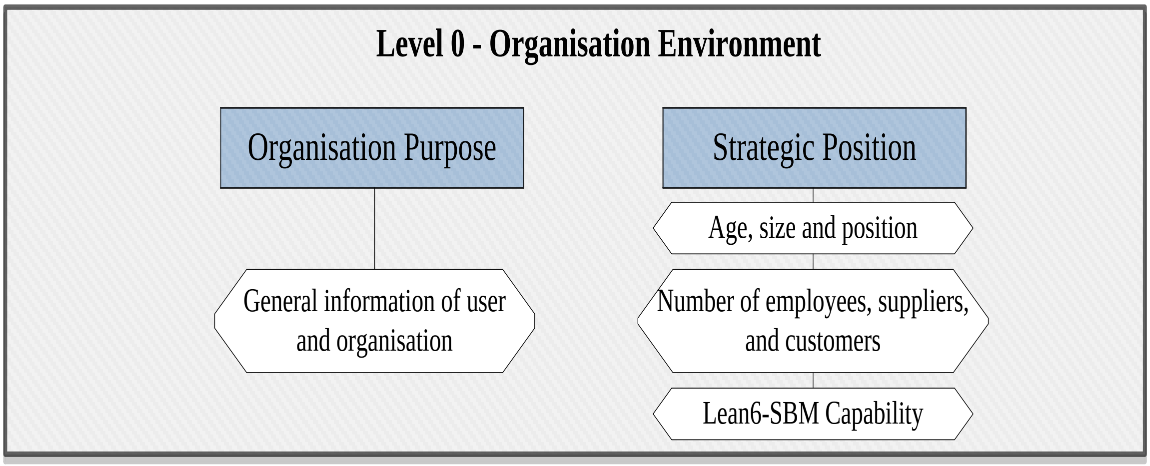


Figure 6. 3 IDEF0 Model of Organisation Environment

In order to start producing the KB rules for this stage, the IDEF0 diagram should be illustrated in a process flow chart form as shown in Figure 6.4. The process starts by detecting the organisation’s purpose followed by the organisation’s strategic position. For each category (i.e. purpose or position) the KB rules are designed as questions to be answered by the concerned user according to the degree of his/her responsibilities. The user feedback must be verified at the end of the process, and the information is stored and transferred to trigger the *Organisation Business Perspective* module.

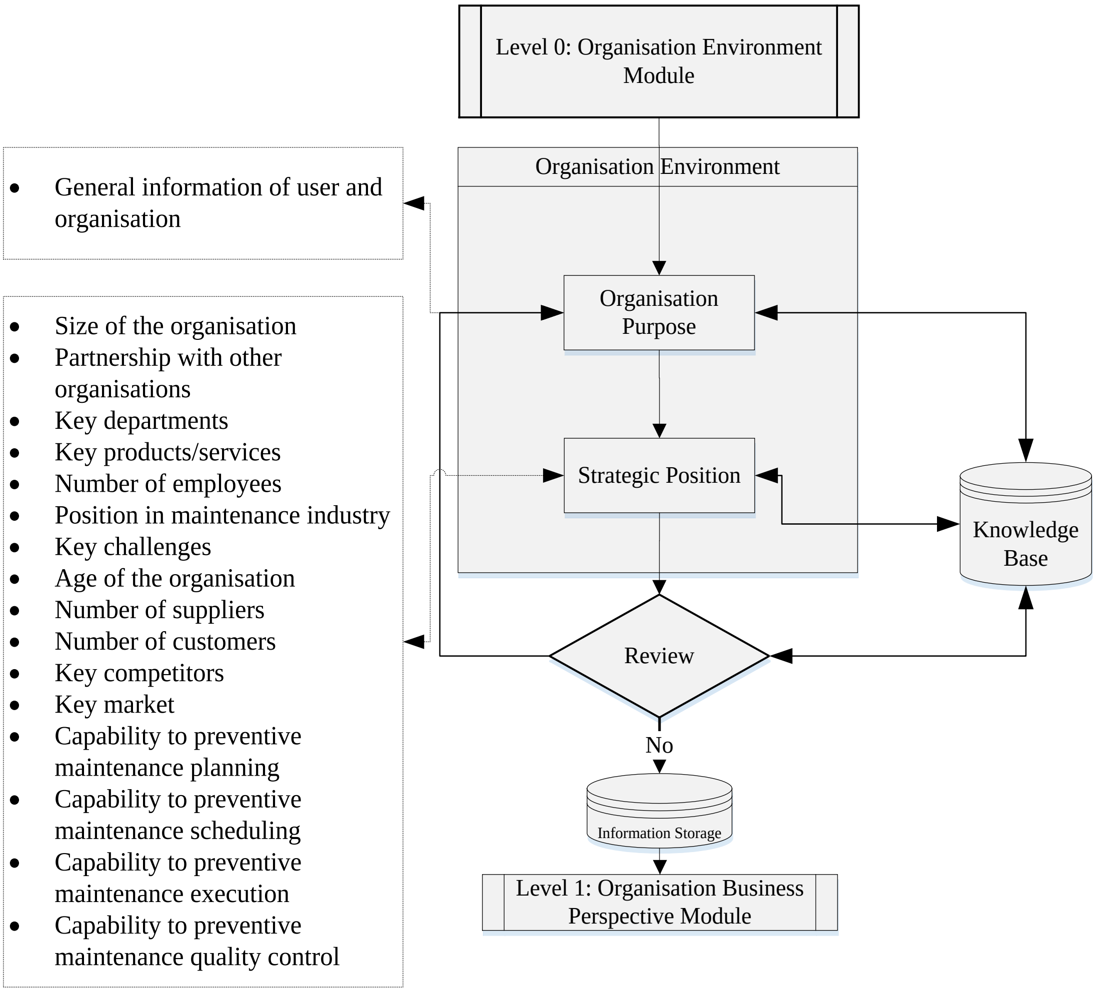


Figure 6. 4 Flow Chart for Organisation Environment Module

Based on the designed flow chart (Figure 6.4), the user will be asked initially to input general information such as the name of the user, his/her position in the organisation, and the organisation address. This information will be useful for tracing the input validity. The KB rules will be fired in sequence acquiring more information to identify age and size of the organisation, partnership type (autonomous, partner, or linked), and position in the maintenance strategic system. These are important in order to establish an overview of the organisation's economic situation. In addition, the information of key departments, key services, number of employees, number of suppliers and customers, key competitors, and the organisation's capability in preventive maintenance activities during the last 10 years is required to know the strength of the relationship between different stakeholders, and the capability of investment in long-term activities. The following example of the KB rules set investigates the size of the organisation based on the flow of the *Organisation Environment* module:

```
IF     the organisation has less than 10 employees
AND the organisation has annual turnover less than or equal to € 2 million
OR the organisation has balance sheet total less than or equal to € 2 million
THEN the organisation is categorised as a micro firm
ELSE IF the organisation has less than 50 employees
AND the organisation has annual turnover less than or equal to € 10 million
OR the organisation has balance sheet total less than or equal to € 10 million
THEN the organisation is categorised as a small firm
ELSE IF the organisation has less than 250 employees
AND the organisation has annual turnover less than or equal to € 50 million
OR the organisation has balance sheet total less than or equal to € 43 million
THEN the organisation is categorised as a medium firm
ELSE the organisation is categorised as a large firm
ENDIF
```

Because this module is intended to deliver a general description of the SBM organisation, GAP analysis will not be considered. Nevertheless, it is applicable for further analysis in collaborative business perspectives. The information collected from this module will be stored in the KB Lean6-SBM System in which it can be loaded to the next modules for the positioning of the Lean6-SBM organisation with the benchmark standard.

6.3 Level 1: Organisation Business Perspectives

In order to achieve a comprehensive assessment for the SBM organisation, there must be an investigation into the organisation's business performance, which will be performed by inspecting the market and financial analysis as shown in Figure 6.5 of the IDEF0 model diagram.

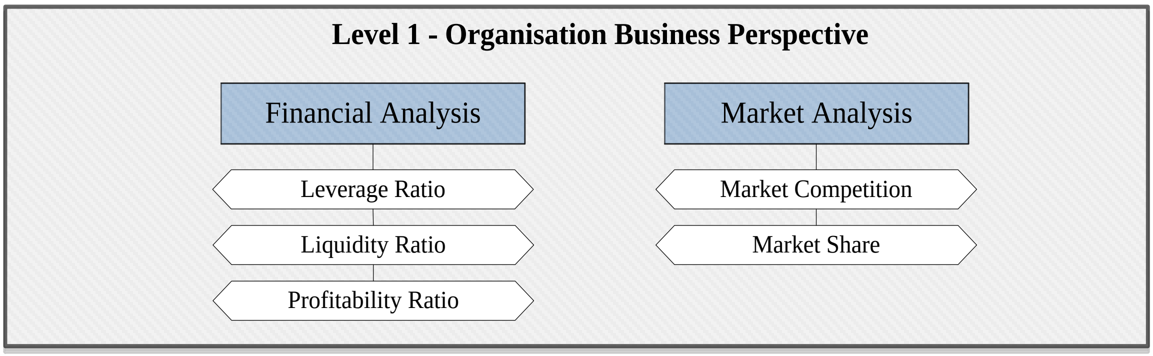


Figure 6. 5 IDEF0 Model for Organisation Business Perspective

Level 1 helps to capture data about the organisation's financial statements, and about the organisation's market analysis in the last three years. The rules developed in the module will establish relationships, converting that data into information. By comparing the level of performance of the organisation with the system benchmark, the module will convert that information into recommendations about which aspects need to be improved in a prioritised manner.

6.3.1 Financial Analysis

The aim of this sub-module is to measure the overall organisation's financial performance in terms of leverage ratio, liquidity ratio, and profitability ratio. Measuring financial performance is mandatory for any business since it indicates how the organisation is run, competes and survives. It also highlights how the organisation provides financial value added to the shareholders (Kaplan and Norton, 1996).

Figure 6.6 illustrates that the assessment of financial analysis is based on calculating *Leverage Ratio, Liquidity Ratio,* and *Profitability Ratio*. These are fundamentally obtained from the *Income Statement, Balance Sheet,* and *Cash Flow* of the organisation for the last three consequent years. Those performance indicators can offer the trend of the organisation's potential in the last three years whether it is improving, fluctuating, declining, or in a steady state position.

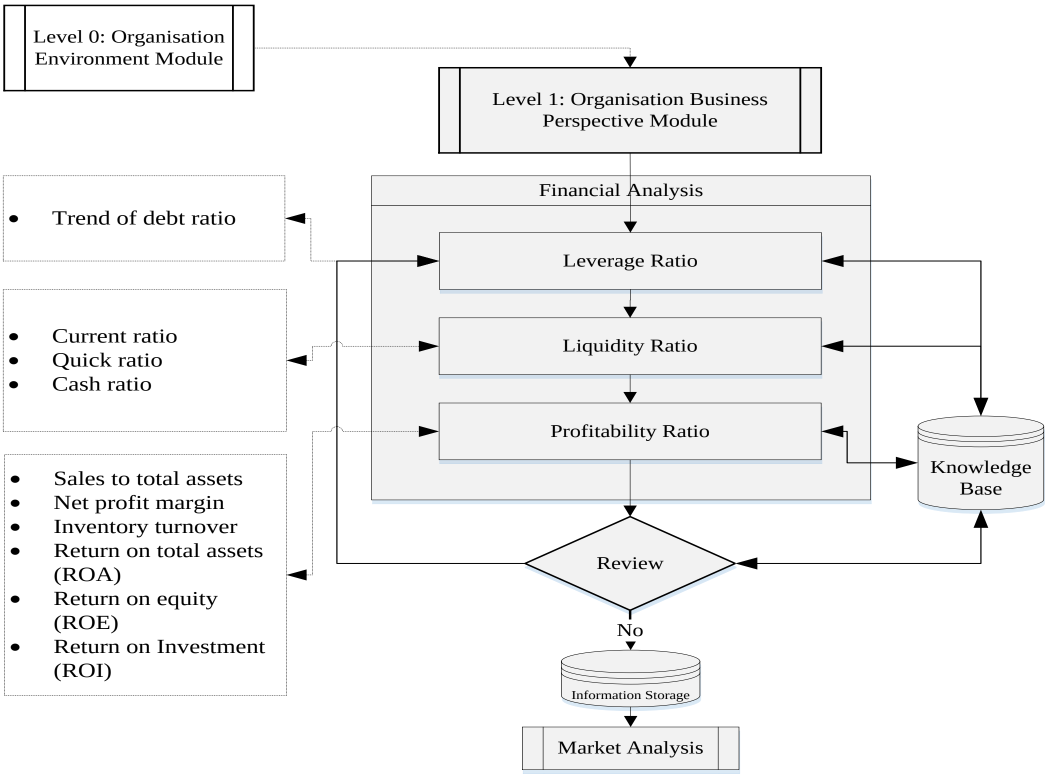


Figure 6. 6 Process Flow Chart of Organisation Financial Analysis Sub-Module

The following example of KB rules set is generated within the organisation's *Financial Analysis* sub- module:

IF *the Net Profit Margin (NPM) in Last Year(LY) > LY-1* (Yes: GP; No: BP-PC-2)

AND *the NPM in LY-1 > LY-2* (Yes: GP; No: BP-PC-2)

AND *the value of the NPM in LY is positive* (Yes: GP; No: BP-PC-1)

AND *the value of the NPM in LY-1 is positive* (Yes: GP; No: BP-PC-2)

AND *the value of the NPM in LY-2 is positive* (Yes: GP; No: BP-PC-3)

AND *the Return on Assets (ROA) in LY > LY-1* (Yes: GP; No: BP-PC-2)

AND *the ROA in LY-1 > LY-2* (Yes: GP; No: BP-PC-2)

AND *the ROA has a positive value in LY* (Yes: GP; No: BP-PC-1)

AND *the ROA has a positive value in LY-1* (Yes: GP; No: BP-PC-2)

AND *the ROA has a positive value in LY-2* (Yes: GP; No: BP-PC-3)

AND *the Return on Investment (ROI) in LY > LY-1* (Yes: GP; No: BP-PC-1)

AND *the ROI in LY-1 > LY-2* (Yes: GP; No: BP-PC-2)

AND *the ROI has a positive value in LY* (Yes: GP; No: BP-PC-1)

AND *the ROI has a positive value in LY-1* (Yes: GP; No: BP-PC-2)

AND *the ROI has a positive value in LY-2* (Yes: GP; No: BP-PC-3)

AND *the Return on Equity (ROE) in LY > LY-1* (Yes: GP; No: BP-PC-1)

AND *the ROE in LY-1 > LY-2* (Yes: GP; No: BP-PC-2)

AND *the ROE has a positive value in LY* (Yes: GP; No: BP-PC-1)

AND *the ROE has a positive value in LY-1* (Yes: GP; No: BP-PC-2)

AND *the ROE has a positive value in LY-2* (Yes: GP; No: BP-PC-3)

THEN *the organisation profitability is acceptable and increased in last three years*

OR *the organisation profitability is below the acceptable limit and hence a risk analysis has to be carried out*

In the above KB rules, the system starts questioning the user regarding the different ratios in the financial statements. The system has categorised the organisation as having a major problem with category PC-2, if the net profit margin (NPM) value of this year is less than the value of the last year. This is also applicable to other critical financial ratios (i.e. ROA, ROI, and ROE) if they show less value than the previous year. In addition, the KB Lean6-SBM System categorises the organisation as having a serious problem if these values are negative for the last three consecutive years, which means that a proper improvement plan has to be undertaken to increase the profit.

This will be followed by diagnosing the situation of the business in the current market. Each sub-module with related dimensions is linked with the information base and benchmarked with the existing knowledge of the Lean6-SBM standard through the KB database. The user feedback must be reviewed and verified at the end of the process.

6.3.2 Market Analysis

This sub-module is designed to get an overview of the organisation’s competition environment and its trends in the last three years. It will also show the percentage of market share amongst other building maintenance organisations. According to Tan et al. (2014) and Singh et al. (2016) it is important to measure an organisation’s market share as it gives an indication of effective maintenance management compared to other competitors and based on its market target.

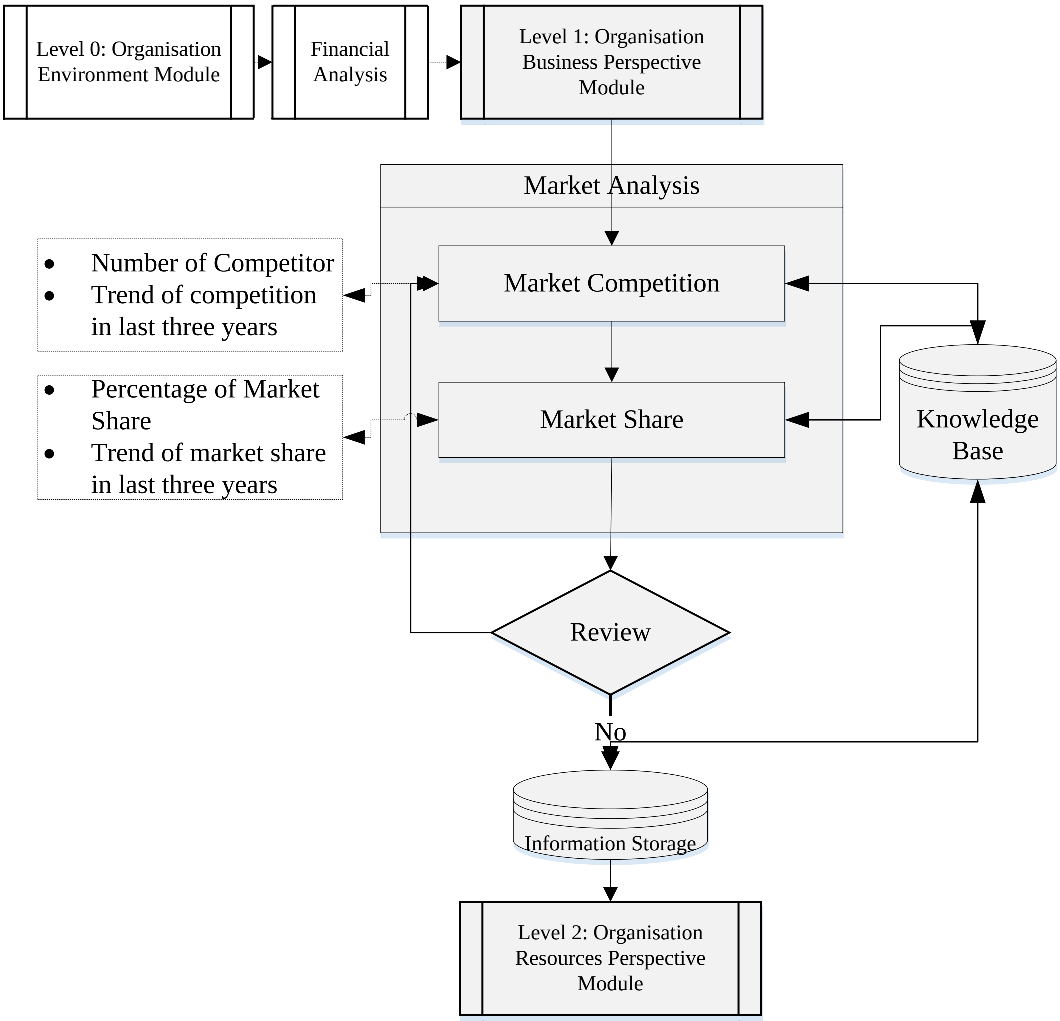


Figure 6. 7 Process Flow Chart of Organisation Market Analysis Sub-Module

Figure 6.7 shows the process flow chart of the *Market Analysis* sub-module, which consists of a *Market Competition* and a *Market Share* dimension. With regard to *Market Competition,* the information acquired is related to competitors who are involved in the Lean6-SBM environment and have had the same level of competencies for the last three years. This will help in identifying the organisation's trend of *Market Competition*. However, the percentage of business received will be used for the *Market Share* analysis that will also help in identifying the trend of *Market Share* in the last three years. The following example of KB rules set is generated within the organisation's *Market Analysis* sub-module:

IF *The organisation percentage share with respect to the overall SBM market share is measured in last three years (Yes: GP; No: BP-PC-2)*

AND *The organisation percentage share in 'last year = 2 years ago = 3 years ago'*

THEN *The organisation market share is 'Constant for the last three years'*

ELSE IF *The organisation percentage share in 'last year > 2 years ago >= 3 years ago'*

THEN *The organisation market share is 'Good for the last three years'*

```
ELSE IF   The organisation percentage share in 'last year < 2 years ago =< 3 years ago'
THEN      The organisation market share has 'Dropped in last three years'
ELSE      The organisation market share is 'Fluctuated and needs attention'
ENDIF
```

In the above KB rules, the user is initially asked if the organisation has measured its percentage of market share in the last three years. If the answer is 'No', the KB System assumes that no information is provided and hence categorises the organisation as having a serious problem (PC-2). If the user answer is 'Yes', the System will check the increment/decrement in relationships during the last three years in which the trend can be easily identified.

6.4 Level 2: Organisation Resources Perspective

Assessment of resources is critical in a maintenance environment because it measures the capability of the organisation to cope with new changes (Waldeck, 2014). The three main pillars in this perspective are *Human Resource*, *Technology Resources*, and *Financial Resource* as represented in the IDEF0 model shown in Figure 6.8.

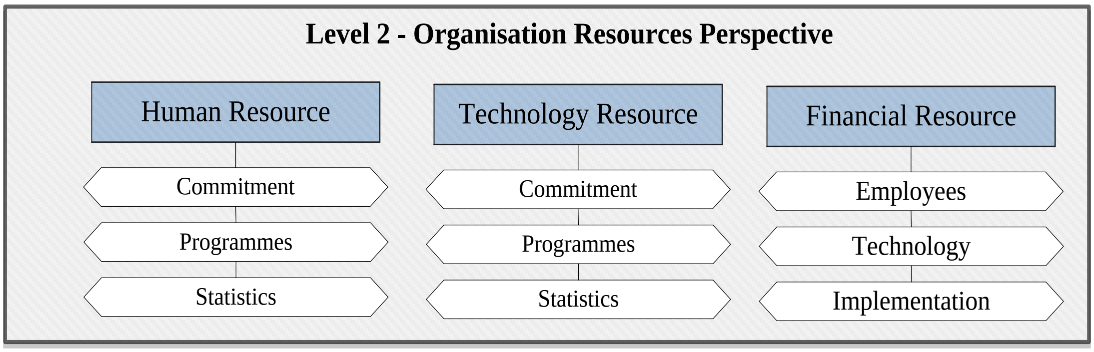


Figure 6. 8 IDEF0 Model of Organisation Resources Perspective

Therefore, *Level 2: Organisation Resources Perspective* helps to capture data about the organisation's human, technology, and financial resources, and about the organisation's performance in these aspects. The rules embedded in the module will establish relationships, converting that data into information. By comparing the level of performance of the organisation with the system benchmark, the module will convert that information into recommendations about strategic issues of the organisation's resources (knowledge or know-how).

6.4.1 Human Resource

Human Resource is the backbone of technology applied and financial support to achieve an organisation's competitiveness. One of the key attributes in world-class manufacturing is when others are continually seeking to attract other's employees due to their skills and effectiveness (Tabassi et al., 2012). The main objective of this sub-module is to evaluate the *Human Resource* capabilities through continuous development in the recruitment process, employee satisfaction, training, and empowerment. During the assessment process, the system will focus on three core elements within *Human Resource*. These include commitment to human resource development (HRD) from all managerial levels, short-term and long-term programmes, along with employee participation and statistics that cover employees' qualifications, employee turnover, absenteeism, and training.

The importance of human resource attributes has been proven in terms of increasing productivity in construction companies (Tabassi et al., 2012), which is relatively close to the building maintenance context; it therefore represents a critical point to be assessed in a Lean6-SBM organisation.

Figure 6.9 illustrates the process flow chart of developing the KB rules for the *Human Resource* sub-module. It includes the three main dimensions that have been depicted earlier in Figure 6.8; these are *Commitments*, *Programmes*, and *Statistics*. The figure shows that for the *Human Resource* sub-module, the KB System starts investigating the involvement of different managerial levels in decision-making, HRD programmes development, HRD budget allocation, and determination of HRD performance indicators. These are examined under the organisation's *Commitment* towards *Human Resource*. The KB System then evaluates the organisation's HRD programmes that have been classified into long-term, short-term, and management aspects. In the long-term aspect, a question like "Does the organisation establish a system and procedures for job and career path development?" is asked, whereas in the short-term aspect the question can be "Does the organisation establish a system for evaluation of employees' performance?". In terms of management, the system evaluates its availability and support to HRD improvement programmes.

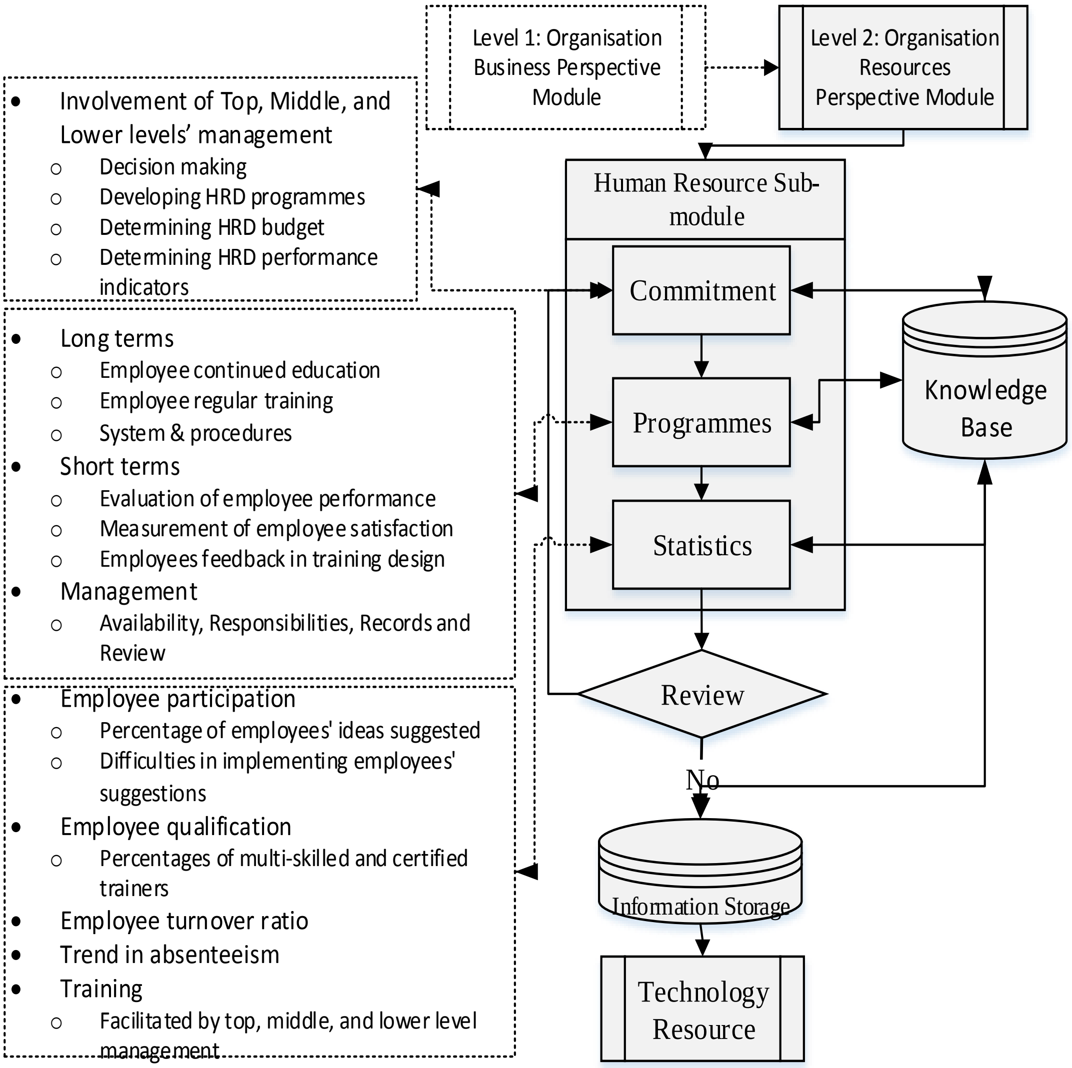


Figure 6. 9 Process Flow Chart of Organisation Human Resource Sub-Module

The final assessment in this sub-module is the *Statistics* on *Human Resource* achievements. In this regard, the KB System starts by identifying the existence of successful employees' participation in the development of HRD programmes, followed by capturing the workforce qualifications, turnover, absenteeism, and training facilitated by different managerial levels. Brusco and Johns (1998) emphasised the importance of having a multi-skilled workforce in productivity within the technical environment like building maintenance. In fact, this productivity can easily be affected by employee turnover and absenteeism.

The following example of KB rules set is produced within the organisation's *Human Resource* sub-module:

IF *The organisation management has accommodated employees' suggestions in HRD programme for the last three years (Yes: GP; No: BP-PC-2)*

AND *The number of HRD ideas suggested in last 3 years is recorded (Yes: GP; No: BP-PC-2)*

AND *The number of HRD ideas discussed in last 3 years is recorded (Yes: GP; No: BP-PC-2)*

AND *The percentage of HRD ideas (discussed/suggested) for the last year is (>90%: GP; 80<&<=90%: BP-PC-4; 70<&<=80%: BP-PC-3; 60<&<=70%: BP-PC-2); <=60%: BP-PC-1)*

AND *The percentage of HRD ideas (discussed/suggested) for the two years ago is (>90%: GP; 80<&<=90%: BP-PC-4; 70<&<=80%: BP-PC-3; 60<&<=70%: BP-PC-2); <=60%: BP-PC-1)*

AND *The percentage of HRD ideas (discussed/suggested) for the three years ago is (>90%: GP; 80<&<=90%: BP-PC-4; 70<&<=80%: BP-PC-3; 60<&<=70%: BP-PC-2); <=60%: BP-PC-1)*

THEN *The employees' participation through ideas' suggested is highly considered by the organisation*

OR *The organisation is weak with regards to employees' participation*

The above KB rules examine how far the employees' participation with regards to ideas suggested is considered by the organisation, where the user is initially asked if the organisation has accommodated an employees' suggestions programme in the last three years. According to Shuck and Wollard (2010), encouragement of employees to participate in HRD improvement activities is crucial for an organisation which aims to achieve business excellence objectives. Thus, the answer 'No' in the first three questions has been categorised as a serious problem for the organisation. On the other hand, the availability of records in ideas suggested and discussed will enable determination of the percentage of the ideas discussed/suggested, in which the KB System has rated the degree of the answer obtained to be serious if the answer is less than or equal to 70%.

6.4.2 Technology Resource

Albliwi et al. (2014) described the lack of resources as one of the main critical failure factors in implementing LSS. Therefore, it is critical to ensure the capability of *Technology Resource* as it has been proven from the literature that a high correlation exists between the capital maintenance and technology adoption (Boucekkine et al., 2006).

The main objective of this sub-module is to evaluate the *Technology Resource* capabilities through continuous development of technological aspects. During the assessment process, the system will focus on three core elements within the *Technology Resource*. These include: commitment to technology improvement from all managerial levels, organisation programmes to support technology development, and statistics of technology implemented in the last three years.

Figure 6.10 demonstrates the process flow chart of the *Technology Resource* sub-module. It is composed of three dimensions, with similar terms as in *Human Resource* (i.e. *Commitments*, *Programmes*, and *Statistics*). The KB System establishes the assessment of this sub-module through the dimension of *Commitments* by determining the involvement of top, middle, and lower level management in decision making related to technology improvements, technology development programmes, and budget allocated to technology improvements. Again it is essential to engage employees from different levels in technology aspects due to the fact that any success in implementing LSS requires a generation of continuous improvement initiatives from employees in different organisation levels.

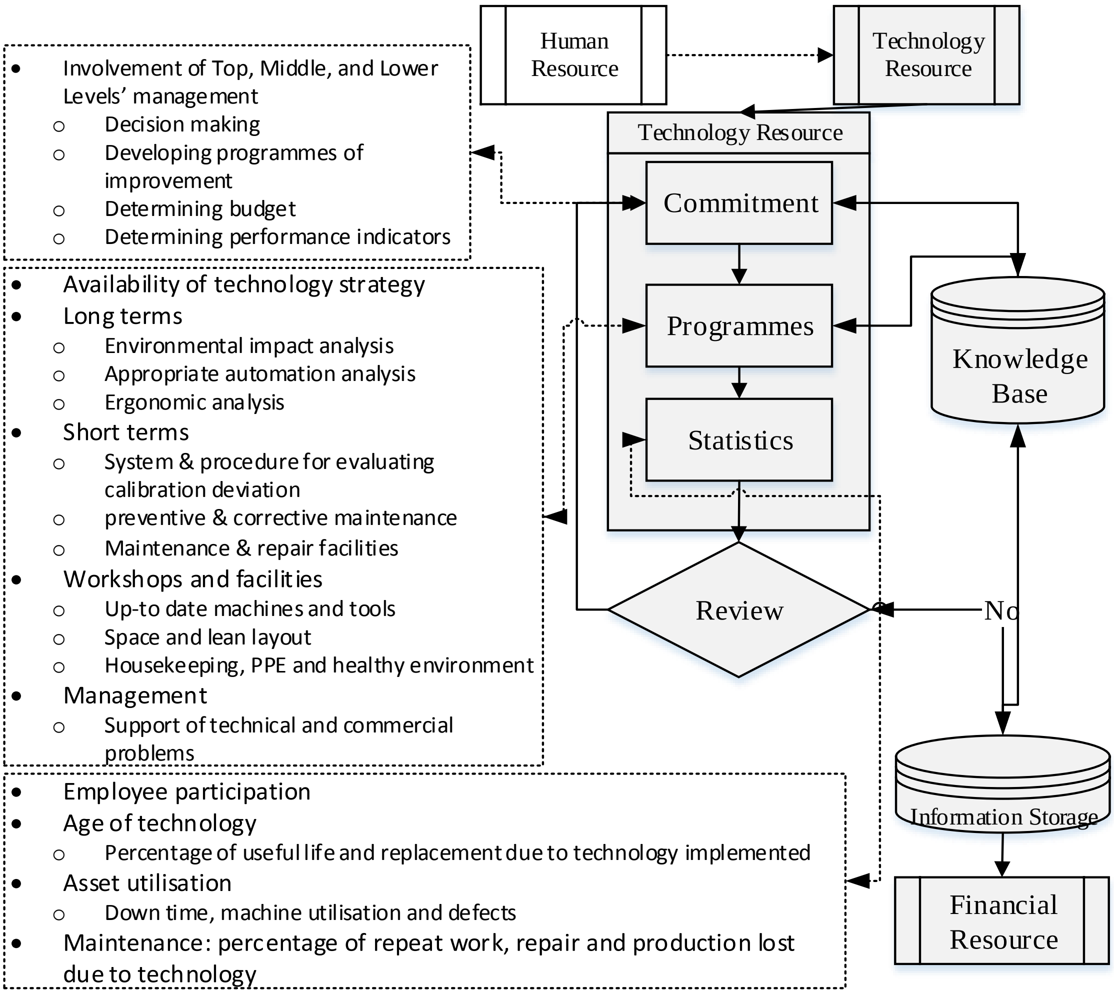


Figure 6. 10 Process Flow Chart of Technology Resource Sub-Module

The next step is to assess the organisation's *Programmes* with respect to technology improvements. The KB System starts by investigating the availability of establishing a technology strategy with respect to the future technology demand needed to compete, level of investment needed to grow, and assets needed to provide sustainability. The system will then evaluate the long-term and short-term programmes that support technology. This is followed by diagnosing the applicability and readiness of the workshops and facilities to the layout setup required by the transformation process. In addition, the *Programmes* dimension has been designed to check the management difficulties and degree of support with regards to resolving technical and commercial problems in a maintenance environment (Ishikura, 2010). The last dimension in this sub-module is *Statistics*, where the KB System begins to identify statistically the power of employees' participation and engagement in technology improvements, followed by assessing the measurement of life cycle, downtime, machine utilisation, and unit defects of technology implemented. The assessment is completed by identifying the percentages of maintenance repair and rework activities in the last three years.

The following example of KB rules set is produced within the organisation's *Technology Resource* sub-module:

IF *The organisation has a workshop facility with the required offices, machineries, and tools to carry out preventive maintenance activities (Yes: GP; No: BP-PC-1)*
AND *The organisation has provided up-to date machines and tools required to run the preventive maintenance activities (Yes: GP; No: BP-PC-3)*
AND *All of machine/tool operators do know how to operate the machine(s)/tool(s) (Yes: GP; No: BP-PC-1)*
AND *The organisation has considered enough space and lean layout of workshop facilities (Yes:GP;No:BP-PC-1)*
AND *The organisation has considered housekeeping of workshop facilities (Yes: GP; No: BP-PC-1)*
AND *The organisation has considered proper ventilation in workshop facilities (Yes: GP; No: BP-PC-1)*
AND *The organisation has considered healthy environment of workshop facilities (Yes: GP; No: BP-PC-1)*
AND *he organisation has provided Personal Protective Equipment (PPE) in workshop facilities (Yes: GP; No: BP-PC-1)*
AND *The organisation has provided guidelines in how to use PPE in workshop facilities(Yes:GP;No:BP-PC-1)*
THEN *The organisation's workshop facilities are suitable for LSS transformation*
OR *The organisation needs to improve workshop facilities*

In the above rules, the user is asked if his/her organisation has a workshop facility at the preventive maintenance site office. In fact, having a workshop with a proper site layout and related facilities is very important for the PM team as it incubates the transformation of a culture and team-building process in addition to other office and technical work activities. Thus, the absence of a workshop facility in this regard is rated as PC-1. The KB System is proceeded with investigating whether the machines and tools required to run the business are up to date. In spite of the importance in keeping up to date with technology manufacturers, the case in building maintenance activities is different where basic tools and equipment could be fit for purpose. Therefore, the absence in this rule has been rated as PC-3 (i.e. not a serious issue). The following rules are logically evaluating the know-how operation, space, and workshop layout, housekeeping, ventilation, and personal protective equipment (PPE), which are crucial to consider, based on Lean6-SBM benchmark requirements, and hence, they have been rated as serious problems (PC-1) if the user answer is ‘No’.

6.4.3 Financial Resource

Ahmedbahwa (2014) has elaborated the best practice in various aspects within a HR budgeting scheme (e.g. salaries and benefits, training and development), although this always depends on an organisation’s goals and objectives. Ishikura (2010) highlighted that being aware of the budget allocation in maintenance technology contribution is important for researchers and policies development. On the other hand, asset-based budgeting is required to achieve high performance in terms of asset utilisation, safety, health, and sustainable environment (Jonker, 2017).

The main objective of this sub-module is to investigate the financial capabilities to support Lean6-SBM implementation. With regards to employees, the organisation’s capability will be assessed by checking the budget allocated for training and development, hiring, and benefits. On the other hand, focusing on technology involves checking the budget allocated for improving maintenance tools/equipment, maintaining the asset management system, and maintenance process improvement. Finally, from the implementation perspective, the assessment will trace the annual budget allocation to implement maintenance activities, and asset performance measurements during the last three years.

Figure 6.11 illustrates the process flow chart of the *Financial Resource* sub-module. It consists of three dimensions: *Employees*, *Technology*, and *Implementation*. The KB System establishes the assessment of this sub-module through the dimension of *Employees* by identifying the percentage of the budget allocated to employees (salaries and benefits, staff training and career development, and consultation for improving productivity) from the percentages of the sales turnover in the last three years.

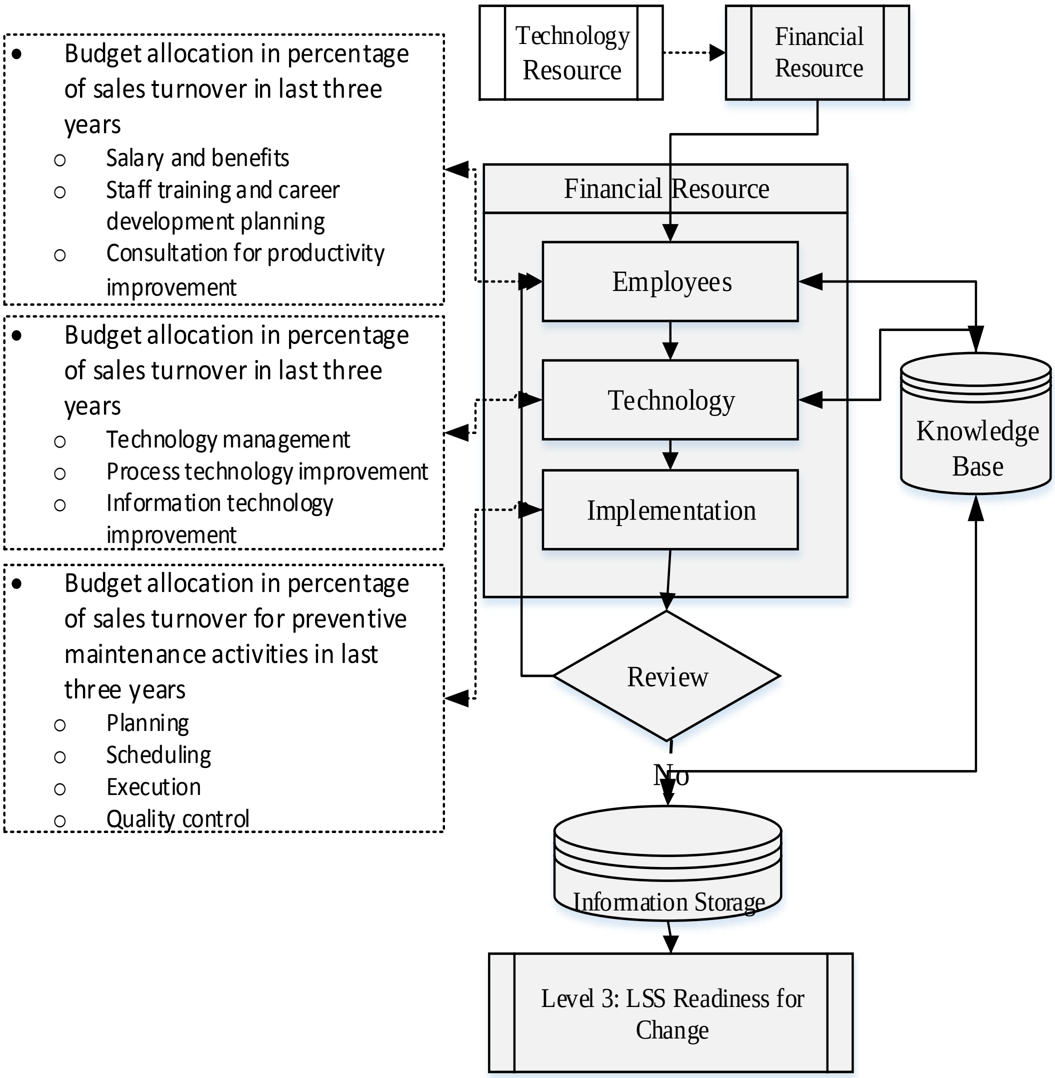


Figure 6. 11 Process Flow Chart of the Financial Resource Sub-Module

Based on the *Technology* dimension, the KB System will proceed to determine the percentage of the budget allocated to improve technology management, process technology, and information technology from the annual sales turnover in the last three years. Finally, this sub-module will conclude by investigating the percentages of budget allocated to different PM activities with respect to the organisation’s assets.

The following example illustrates the KB rule set of the sub-module *Financial Resource* in the *Organisation Resources Perspective* module:

```
IF      The budget allocation (in percentage of sales turnover) for the PM ‘Planning’ activity in the last year is
AND     The budget allocation (in percentage of sales turnover) for the PM ‘Planning’ activity two years ago is
AND     The budget allocation (in percentage of sales turnover) for the PM ‘Planning activity three years ago is
THEN    The organisation has a good contribution towards planning PM in last three years
ELSE IF The budget allocation (in percentage of sales turnover) for the PM ‘Scheduling’ activity in the last year is
AND     The budget allocation (in percentage of sales turnover) for the PM ‘Scheduling’ activity two years ago is
AND     The budget allocation (in percentage of sales turnover) for the PM ‘Scheduling’ activity three years ago is
THEN    The organisation has a good contribution towards scheduling PM in last three years
ELSE IF The budget allocation (in percentage of sales turnover) for the PM ‘Execution’ activity in the last year is
AND     The budget allocation (in percentage of sales turnover) for the PM ‘Execution’ activity two years ago is
AND     The budget allocation (in percentage of sales turnover) for the PM ‘Execution’ activity three years ago is
THEN    The organisation has a good contribution towards executing PM in last three years
ELSE IF The budget allocation (in percentage of sales turnover) for the PM ‘Quality control’ activity in the last year is
AND     The budget allocation (in percentage of sales turnover) for the PM ‘Quality control’ activity two years ago is
AND     The budget allocation (in percentage of sales turnover) for the PM ‘Quality control’ activity three years ago is
THEN    The organisation has a good contribution towards Quality control in PM in last three years
ELSE    The organisation has bad commitment towards budget allocation of PM activities
ENDIF
```

(>5%:GP; 2.5-5%: BP-PC-4; 1-2.5%: BP-PC-3; 0.5-1%: BP-PC-2); <0.5%: BP-PC-1)

The above KB rules show the scenario of the assessment that takes place in the dimension of *Implementation* within this sub-module. Firstly, the user is asked if the percentage of the budget allocated to PM planning in the last three consequent years is greater than 5%, in which it has been used as good practice in this system. However, if the answer is less than or equal to 5%, then the organisation is facing problem categories (PCs) where it becomes the worst (PC-1) if the percentage is less than 0.5% (the KB Lean6-SBM benchmark in this case is set at >5%:GP; 2.5-5%: BP-PC-4; 1-2.5%: BP-PC-3; 0.5-1%: BP-PC-2; <0.5%: BP-PC-1). The KB System will terminate the triggered rules with ***ENDIF*** if the *Planning* activity is seen to be allocated with enough budget in the last three years, otherwise a similar set of rules will be triggered to determine if the *Scheduling* activity was considered. Again, if the *Scheduling* activity gets any PC, the next set of rules are fired where the activities of *Execution* and *Quality Control* are evaluated respectively.

6.5 Level 3: LSS Readiness for Change

An organisation's resistance to change is considered to be one of the critical failure factors against implementing LSS as explained in Chapter 3. According to Hanafizadeh and Ravasan (2011), a change management framework evaluation has to address staff, skills, style, shared values, systems, structure, and strategy. On the other hand, Gerbec (2016) has integrated goals, human resource, technology, and management as part of the Plan, Do, Check, and Act (PDCA) organisation's improvement cycle. This module (*LSS Readiness for Change*) will focus on *ICT*, *Share Values*, and *Soft TQM* as depicted in Figure 6.12 which shows its IDEF0 model.

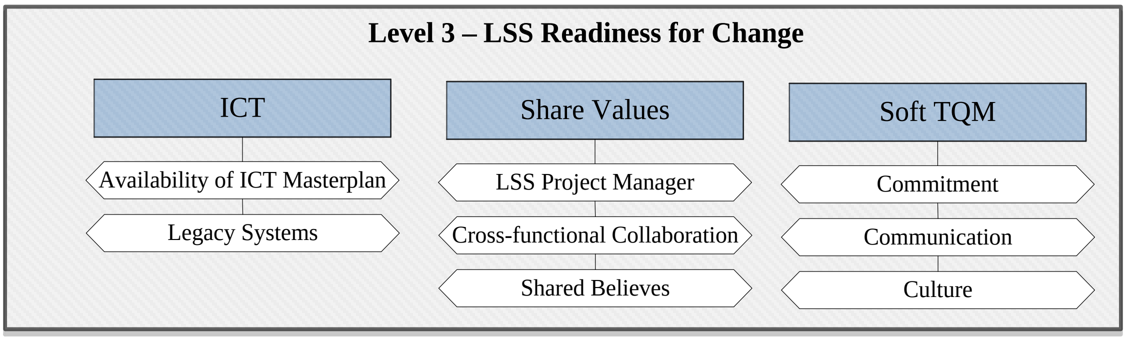


Figure 6. 12 IDEF0 Model of LSS Readiness for Change

Level 3 LSS Readiness for Change assists in capturing data about the organisation's ICT development, share values, and about the organisation's TQM achievements. The rules embedded in the module will validate relationships, converting that data into information. By assessing and comparing the level of performance of the organisation with the system benchmark, the module will convert that information into recommendations about strategic issues related to readiness for change.

6.5.1 Information and Communications Technology (ICT)

Hanafizadeh and Ravasan (2011) emphasised that an organisation has to maintain effective system applications for the processes and procedures used to execute a business' daily tasks. The evidence of devoting attention to the impact of ICT on manufacturing development enhances the interface of application and technology perspectives (e.g. quality assurance and cost management). This is to ensure maximising the performance and competitive positioning in the marketplace (Ritchie and Brindley, 2005).

This sub-module is developed to investigate the ICT capabilities in a Lean6-SBM organisation. With regards to the availability of an ICT master plan, the organisation's capability will be assessed by evaluating the ICT workforce development, network availability, and the integration between the network platforms. On the other hand, focusing on legacy systems involves checking the availability of technical system support, the functionality with respect to the core business, the originality of system architecture, and the fulfilment of the system technology to new requirements. The system will test the implementation of the PDCA cycle in both dimensions.

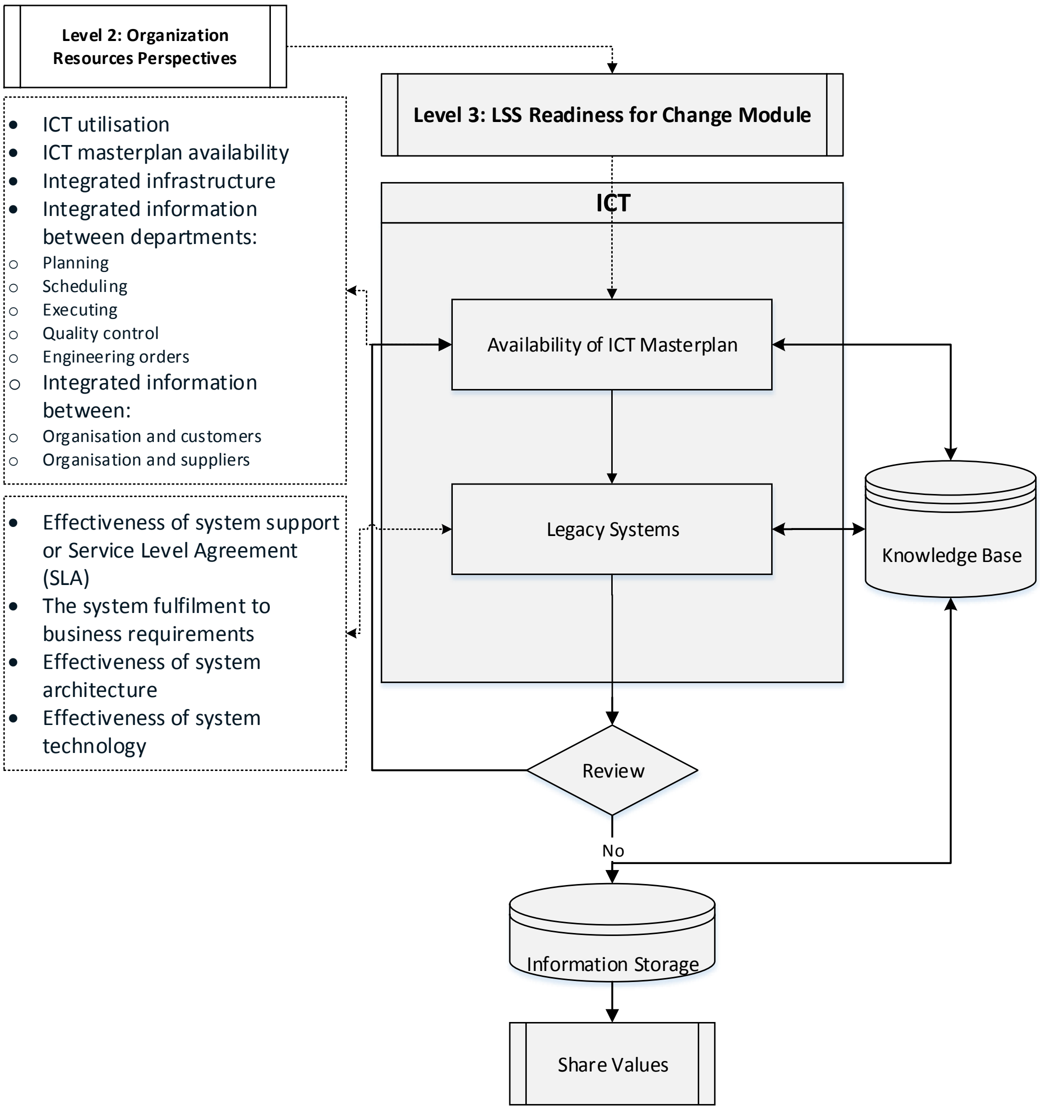


Figure 6. 13 Process Flow Chart of ICT Sub-Module

Figure 6.13 illustrates the process flow chart of the ICT sub-module in which the KB System begins the assessment by identifying whether the organisation has implemented programmes (in the dimension of *Availability of ICT Master Plan*) like developing ICT workforce, standardisation of business process, system integration, and network communication to improve technology utilisation. This is followed by investigating the current ICT master plan and its efficiency in aligning the organisation's systems and procedures. Furthermore, hard (infrastructure) and soft (information) integration between PM departments in addition to soft integration with customers and with suppliers are designed to be evaluated in the following stage.

The assessment of the *Legacy Systems* dimension comes next in which the KB System has to check the effectiveness of how the current legacy systems are implemented and used by the departments. This test includes four different perspectives: system support (internal/external), fulfilment of business requirements, system architecture, and the technology implemented.

The following example of KB rules set is generated within the *Legacy Systems* dimension:

IF *The organisation has identified the main software/legacy system that run the business (Yes: GP; No: BP-PC-1)*

AND *The effectiveness of support or Service Level Agreement (SLA) of the legacy system/s within the organisation in last 3 years have been measured (Yes: GP; No: BP-PC-1)*

AND *The effectiveness of SLA for legacy system/s within the organisation in last year was (>90%: GP; 80-90%:BP-PC-4; 70-80%: BP-PC-3; 60-70%:BP-PC-2; <60%:BP-PC-1; Not Available: BP-PC-1)*

AND *The effectiveness of support or SLA for legacy system/s within the organisation in 2 years ago was (>90%: GP; 80-90%:BP-PC-4; 70-80%: BP-PC-3; 60-70%:BP-PC-2; <60%:BP-PC-1; Not Available: BP-PC-1)*

AND *The effectiveness of support or SLA for legacy system/s within the organisation in 3 years ago was (>90%: GP; 80-90%:BP-PC-4; 70-80%: BP-PC-3; 60-70%:BP-PC-2; <60%:BP-PC-1; Not Available: BP-PC-1)*

THEN *The organisation has achieved the Lean6-SBM benchmark of effective SLA in the last three years*

OR *The organisation is weak in sustaining effectiveness of SLA for the last three years*

Diving into the above rules, the KB System begins by asking the user if the organisation has identified the main legacy systems that run the business. In spite of having complete solutions to manage PM activities (e.g. ERP), the practice shows that some organisations run more than one piece of software (e.g. asset management software, inventory software, procurement software) to complete a PM work order life cycle. Regardless of the system type, this study has generalised the assessment under the so-called legacy systems. It is very important to have an effective computerised data management system to manage the PM history and activate concurrent work orders. Therefore, the absence of this aspect leads to a serious problem (PC-1).

If the answer is ‘Yes’, the user will be asked if the system support or service level agreement (SLA) for those legacy systems has been measured in the last three consecutive years. According to Alkazemi (2014), assessing the support of legacy systems is crucial before attempting to replace, maintain, or extend a current system. Thus, the absence in this regard is also rated as a serious problem category (PC-1). The system then proceeds with determining the effectiveness of that support in the last three years in which the good point (GP) is valid only if the effectiveness of the given annual system support is greater than or equal to 90% (90–100%: GP; 80–89%: BP-PC-4; 70–80%: BP-PC-3; 60–70%: BP-PC-2; <60%: BP-PC-1; Not Available: BP-PC-1). The KB System will show that the organisation has achieved the Lean6-SBM benchmark of effectiveness in SLA of legacy system(s) if it has passed all the questions successfully.

6.5.2 Share Values

The main objective of this sub-module is to investigate the Lean6-SBM organisation’s share values and how widely and deeply they are shared by the employees. Three dimensions have been identified here as affecting factors on shared values: *LSS Project Manager*, *Cross-functional Collaboration*, and *Shared Beliefs* (Figure 6.14). The knowledge behind these dimensions are derived from three main sources related to Buthmann and Kaufmann (2015), Luca and Atuahene-Gima (2007), and Amoako-Gyampah and Salam (2004) respectively.

With regards to *LSS Project Manager*, the system will go through assessing whether the selected LSS project manager has enough business knowledge and leadership personality, enough functional know-how competencies, and his/her potentiality to continuously manage the resistance to change.

The second factor is the *Cross-functional Collaboration*, which will evaluate the cooperation between departments, as it forms the degree of cooperation, representation, and contribution of different functional departments to the service or product innovation process (Luca and Atuahene-Gima, 2007).

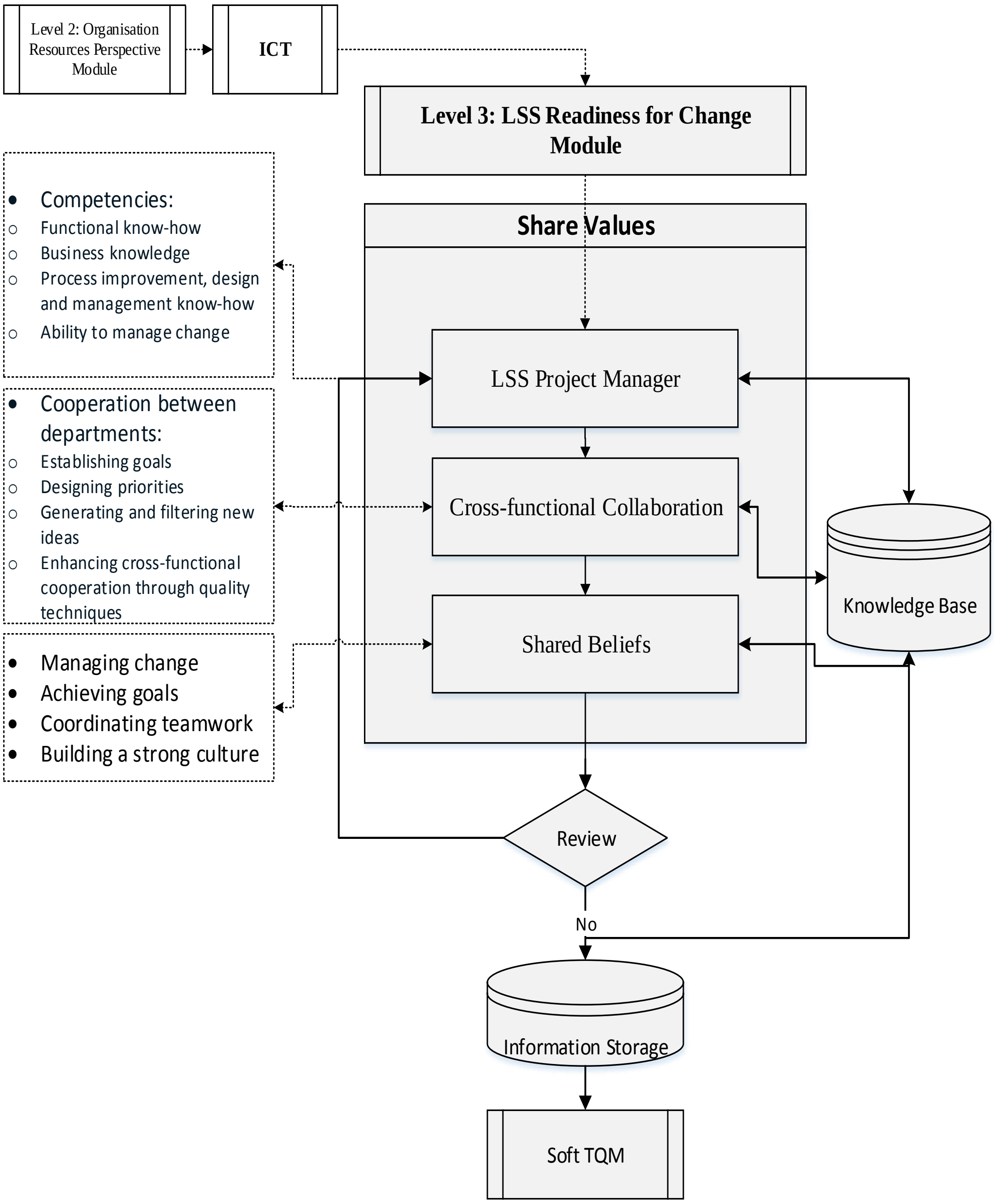


Figure 6. 14 Process Flow Chart of Share Values Sub-Module

The last factor in this sub-module is the *Shared Beliefs*, which refers to the employees' beliefs about the overall impact of the change on the organisation with regard to its benefits (Amoako-Gyampah and Salam, 2004). It is reflected here as a shared belief with employees and managers regarding the benefits of implementing Lean6-SBM. The assessment is highly required for the organisation based on four crucial functions: managing change, achieving goals, coordinating teamwork, and building a strong culture.

The process flow chart shown in Figure 6.14 starts by determining the degree of competencies in the dimension of *LSS Project Manager*. This includes leadership competencies like functional know-how, business knowledge, process know-how (improvement, design, and management), and ability to create and manage change. Next, the KB System will proceed with the dimension of *Cross-functional Collaboration* where the system will evaluate the current situation of cooperation between PM departments. An example of questions that will be asked in this regard is: “Do different departments within your organisation cooperate fully in generating and filtering new ideas with regards to improve maintenance process”, where the possible answers are: ‘Strongly agree’: GP; ‘Agree’: BP-PC-5; ‘Neutral’: BP-PC-4; ‘Disagree’: BP-PC-2; ‘Strongly disagree’: BP-PC-1.

The last dimension in this sub-module is the *Shared Beliefs.* The KB System begins this dimension by investigating the ability to manage change among employees, followed by assessing how far they are defining and achieving their goals, their belief in teamwork, and individual contribution towards building a strong culture.

The following example of KB rules set is produced within the *Share Values* sub-module (the dimension of *LSS Project Manager*):

IF *The percentage of the functional know-how as a leadership competency for your selected LSS project manager is*

AND *The percentage of the business knowledge as a leadership competency for your selected LSS project manager is*

AND *The percentage of the process improvement, design and management know-how as a leadership competency for your selected LSS project manager is*

AND *The percentage of the change leadership ability as a leadership competency for your selected LSS project manager is*

THEN *The organisation has achieved the benchmark for project manager competencies*

OR *The organisation has to optimise the level of project manager competencies*

(25-30%: GP; 31-45%: BP-PC-5, 46-65%: BP-PC-4, 66-85%: BP-PC-3, >85%: BP-PC-1; <25%: BP-PC-1)

The above KB rules trigger the question that seeks the current level of project manager competencies. The user is asked firstly for the percentage of functional know-how competency, followed by the business knowledge, process improvement, and change ability respectively. The benchmark in KB Lean6-SBM for each competency in this study is 25–30%, based on Buthmann and Kaufmann (2015), whereas the other percentages have been categorised in different problem categories (31–45%: BP-PC-5, 46–65%: BP-PC-4, 66–85%: BP-PC-3, >85%: BP-PC-1, <25%: BP-PC-1).

6.5.3 Soft TQM

It has been elaborated from the literature that the high powerful implications are gained from focusing on improving the TQM soft elements (Oakland, 2014). The main objective of this sub-module is to investigate the soft TQM capability in the Lean6-SBM organisation. With regards to *Commitment*, the organisation’s capability assessment will focus on the budget allocated for developing hard TQM pillars (i.e. planning, performance, people, and process) and related achievements for the last three years. Whereas in *Communication*, the evaluation will take place to ensure the effectiveness of internal and external communication between different parties affecting the business process. Finally, from the *Culture* perspective, the assessment will trace the organisational culture towards employees and the management style used to carry out daily routine tasks. These have been designed within the KB System as shown in the process flow chart of Figure 6.15.

The above mentioned flow chart shows that the KB System will start the assessment by identifying the organisation’s commitment towards allocating budget for improving the hard TQM pillars (i.e. Planning, Process, People, and Performance). This is followed by evaluating the degree of commitment from different managerial levels in connection with improving these pillars. Afterwards, the KB System will proceed with the dimension of *Communication* in which the effectiveness of both internal and external communication has to be measured. According to Ken Staller (2015), internal communication is essential across the organisation levels; PM workers need to know what has to be done, when, and who will do each task. Furthermore, engineering instructions need to be addressed on time, and employees’ issues have to be transparently resolved. Furthermore, having effective communication with customers and suppliers will lead to enhancement of the retention of customers and strengthen the relationship with suppliers in which both will help in improving the organisation’s cultural change (Graça and Barry, 2016).

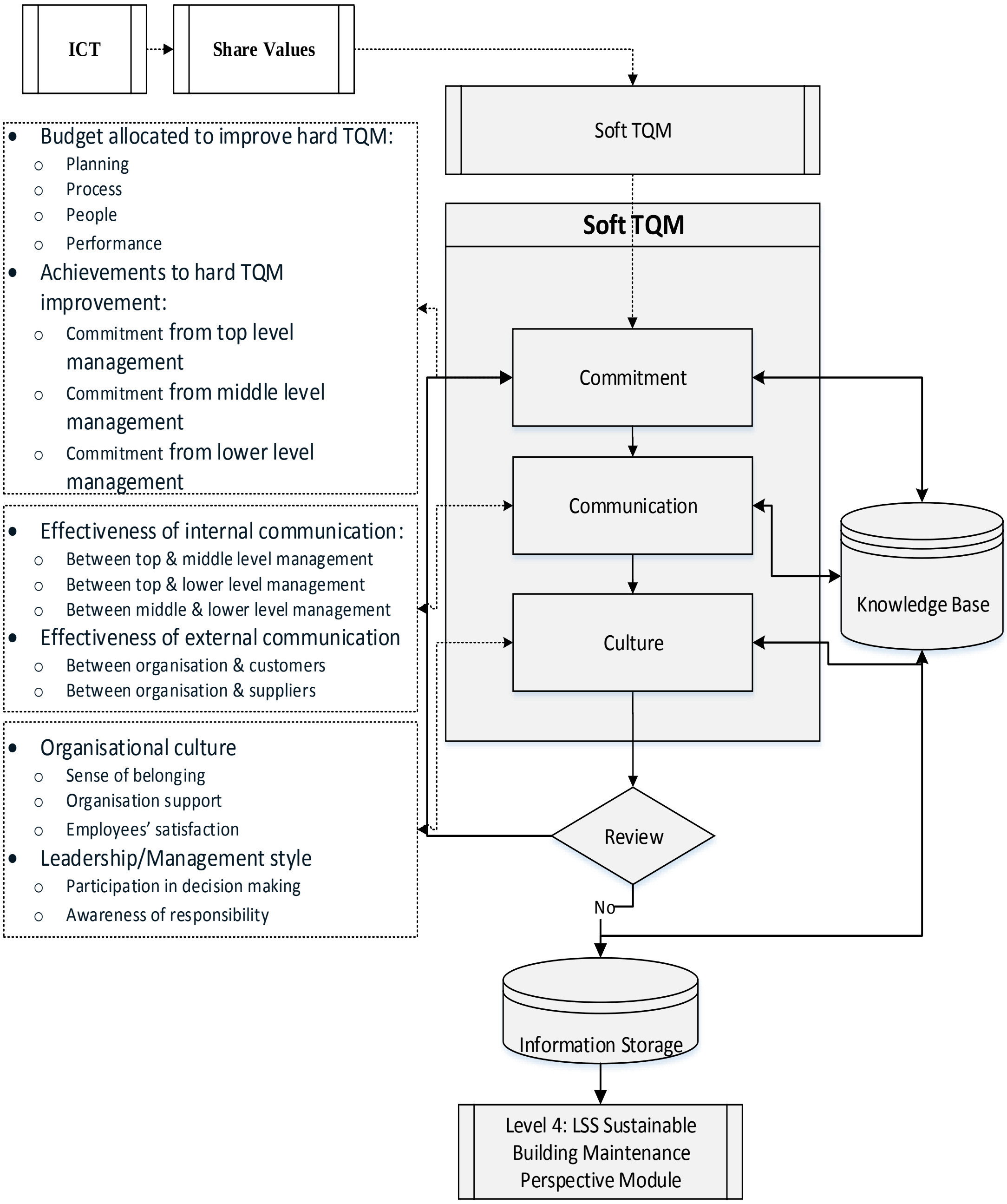


Figure 6. 15 Process Flow Chart of Soft TQM Dimension

This will be motivated by further assessing the dimension of *Culture*. In this regard, the KB System will evaluate the degree of sense of belonging between employees, support of self-expression, and employees' satisfaction. In addition, the dimension will examine the participation of employees in decision-making and their awareness of job responsibilities.

The following example of KB rules set is developed within the sub-module dimension of *Communication*:

IF *The effectiveness of the internal communication between top level management and middle level management in last 3 years has been measured (Yes: GP; No: BP-PC-1)*

AND *The effectiveness of the internal communication between top level management and middle level management in last year was*

AND *The effectiveness of the internal communication between top level management and middle level management in 2 years ago was*

AND *The effectiveness of the internal communication between top level management and middle level management in 3 years ago was*

THEN *The communication effectiveness is good between top and middle level management*

OR *The organisation has to improve the internal communication effectiveness*

(>90%: GP; (80-90%): BP-PC-4, (70-80%): BP-PC-3, (60-70%): BP-PC-2, <60%: BP-PC-1; Not Available: BP-PC-1)

The above KB rules show that the user is initially asked if the effectiveness of internal communication between top and middle level management has been measured in the last three years. Due to the importance of this question, the absence of this aspect has been rated as a critical problem with problem category PC-1. The following questions will identify the percentage of communication effectiveness in each of the last three years based on the user response that will consequently detect the degree of the problematic environment if it exists. Apart from the example, a similar investigation will be carried out between top and lower level management, and between middle and lower level management.

6.6 Level 4: LSS Sustainable Building Maintenance Perspective

This Level is designed to incubate the assessment of the concerned SBM organisation towards implementing LSS. Based on Motawa and Almarshad (2013), the SBM taxonomy has been structured as shown in the IDEF0 model of *LSS Sustainable Building Maintenance Perspective* (Figure 6.16). The main pillars within this taxonomy are *Legal*, *Technical*, and *Administrative* which will be explained in detail in the next sections.

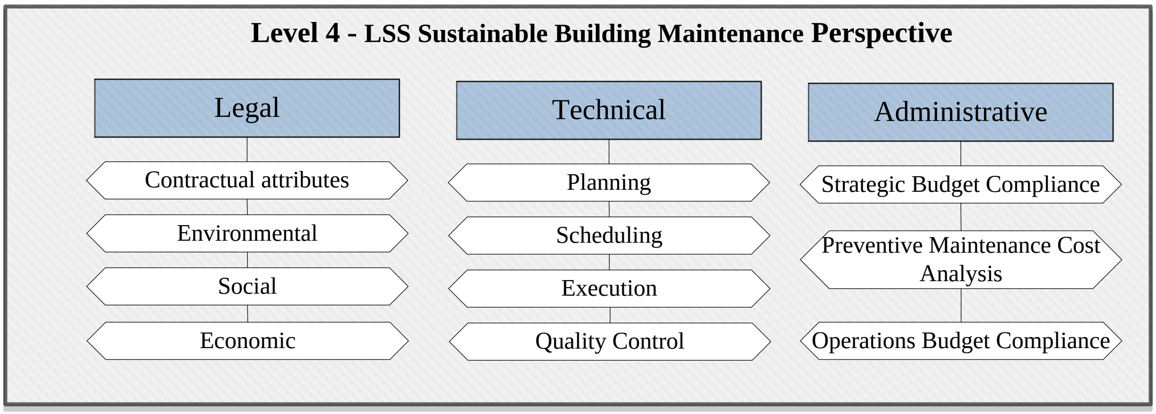


Figure 6. 16 IDEF0 Model of LSS Sustainable Building Maintenance Perspective

Therefore, Level 4 will help to capture data about the organisation's contractual and sustainability attributes, work order lifecycle, and about the organisation's PM administrative commitment. The rules embedded in the module will establish relationships, converting that data into information. By assessing and comparing the level of performance of the organisation with the System benchmark, the module will convert that information into recommendations about the operational issues of the organisation (knowledge or know-how).

6.6.1 Legal

The *Legal* perspective has been integrated as one of the main elements in building maintenance taxonomy as per Motawa and Almarshad (2013). Efficient maintenance of an organisation requires contracts with clear segregation, well-defined scope, specification, and statutory requirements, as well as effective coordination between different departments (Lai et al., 2006). Therefore, this stage has been designed to incubate the contractual main critical and ambiguous attributes along with the environmental sustainability aspects within the SBM taxonomy.

The purpose of this sub-module is to examine the *Legal* aspects according to the organisational performance measurements in sustainable buildings. The centrepiece of the assessment is focused on the contractual attributes and the triple sustainability metrics (environmental, social, and economics). Furthermore, it will ensure the education and training process of the employees based on adopting environmental conscious practice that will help in minimising waste generation and energy consumption.

Figure 6.17 illustrates the process flow chart that assists in developing the KB rules for the *Legal* sub-module. It includes the four main dimensions that have been depicted earlier in Figure 6.16. These are *Contractual Attributes*, *Environmental*, *Social,* and *Economic*.

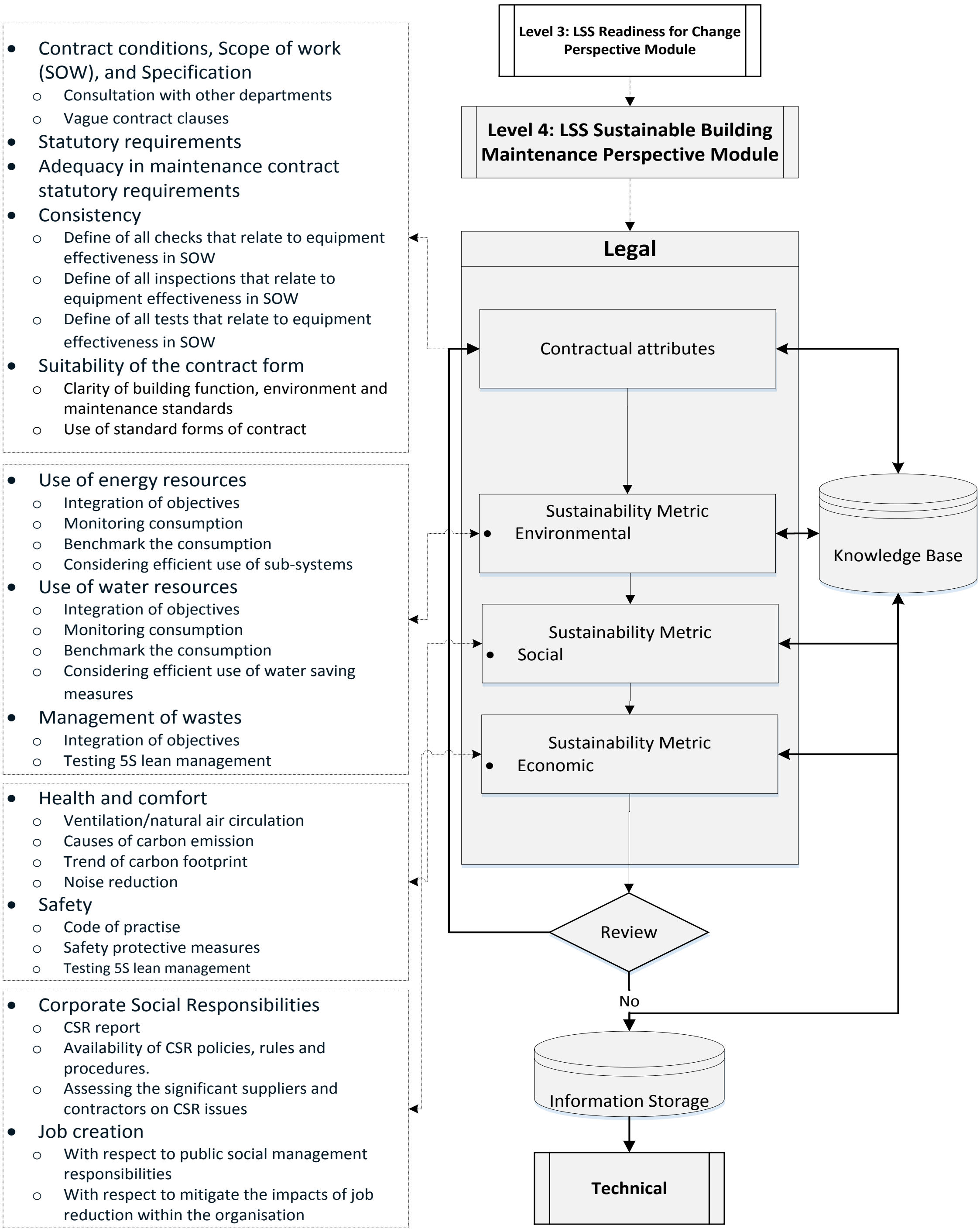


Figure 6. 17 Process Flow Chart of Organisation Legal Sub-Module

The process flow chart of the *Legal* sub-module begins by investigating the role of the SBM organisation in facilitating consultation between internal departments and the effectiveness in dealing with contractual vague clauses; both in terms of drafting and reviewing contract conditions, scope of work, and specification. This is followed by triggering the compatibility of contract clauses with statuary requirements. Furthermore, this dimension (*Contractual Attributes*) will examine the consistency in describing the PM needed for certain equipment and the standardisation in using contractual forms that describe the equipment. According to Lai et al. (2006), having standard forms of contract is very important to ensure availability, clarity, and time-saving in drafting common contract conditions.

The KB System will then proceed to evaluate the triple bottom line of sustainability (i.e. *Environmental*, *Social*, and *Economic*). In the dimension of *Environmental,* the system traces how far the organisation is going in saving natural resources – specifically energy and water. According to Penny (2012), the organisation must have a standard operation manual and an active PM programme in addition to a valid benchmark with a certified energy organisation. In addition to that, the KB System will assess the challenges in managing waste of PM activities as it forms an essential aspect that needs to be tackled with continuous improvement using the 5S Lean management tool.

The second sustainability metric is the *Social*, in which the KB System will examine the current situation in a PM work environment with respect to health, comfort, and safety. In fact, this dimension will check if the organisation has facilitated the basic requirement of health and safety in a work environment according to legal requirements. These include improving buildings' ventilation (Lavy and Bilbo, 2009), reducing carbon footprint (Crown, 2009), reducing noise in the workplace, and adopting an applicable code of practice for safety measures (Hon et al., 2014). Furthermore, the system will assess the implementation of the 5S Lean management tool as it forms an essential part prior to LSS transformation.

The last dimension in the *Legal* sub-module is the *Economic*. In this regard, the organisation will be assessed in its contribution towards corporate social responsibilities (CSR) within local communities and its assistance in job creation for the public in general and for the organisation's terminated employees specifically.

The following set of KB rules is developed within the *Social* dimension in the *Legal* sub-module:

IF *The organisation has put extra effort in to improve safety at the workplace (Daily: GP; Weekly: BP-PC-3, Monthly: BP-PC-2, Yearly: BP-PC-1, Never: BP-PC-1)*

AND *The organisation has carried out tasks or activities that help to improve workplace safety (Daily: GP; Weekly: BP-PC-3, Monthly: BP-PC-2, Yearly: BP-PC-1, Never: BP-PC-1)*

AND *The organisation has followed all safety procedures at maintenance activities (>81%: GP; 61-80%: BP-PC-4, 41-60%: BP-PC-3, 21-40%: BP-PC-2, 0-20%: BP-PC-1)*

AND *The co-workers have followed all safety procedures at maintenance tasks they performed (>81%: GP; 61-80%: BP-PC-4, 41-60%: BP-PC-3, 21-40%: BP-PC-2, 0-20%: BP-PC-1)*

THEN *The organisation is good with respect to safety measures at workplace*

OR *The organisation has not achieved the minimum requirements of safety measures at workplace*

Based on the above KB rules, the KB System begins by asking the user if the organisation has put extra efforts into safety which might include reminding co-workers about safety procedures on a daily basis. In fact, neglecting such a reminder may lead to further negligence from the co-workers during the PM execution phase, and hence unexpected incidents in the workplace. Therefore, the Lean6-SBM benchmark in this aspect is rated as having a serious problem if such an effort is done in a period of one month, and above, or never done at all. The next rule is concerned with addressing critical activities like attending safety meetings or receiving safety training; it has the same rating process as the previous rule. To complete the safety measures' assessment, the last two rules determine the percentages of adopting safety procedures by the organisation and the co-workers respectively. The Lean6-SBM benchmark in this regard is set as having a serious problem if the user response varies between 0%–40%.

6.6.2 Technical

The purpose of this sub-module is to examine the technical aspects according to the organisational performance measurements in the SBM context. The centrepiece of the assessment is focused on planning, scheduling, executing, controlling, and obtaining the required functional system performance. The *Technical* sub-module will assess the current status with benchmarks of managing work order backlogs in the Lean6-SBM organisation. Kaufman and Balsley (2009) elucidated the need to check the lead time of the maintenance work orders' life cycle and how they fulfil the desired specifications and standards.

Figure 6.18 shows the process flow chart of developing the KB rules for the *Technical* sub-module. This sub-module is composed of four main dimensions derived from the PM work order life cycle. These are: *Planning*, *Scheduling*, *Execution,* and *Quality Control*. The KB System establishes the process by triggering the dimension of *Planning*. The System will check the availability of the PM planning department and whether this department is adopting a certified code of practice for maintenance tasks planning. Afterwards, the System will evaluate the responsibilities of the PM planner (e.g. planning shutdowns, turnarounds, assigning work standards, assigning work resources) and the performance of applying them to the desired standard. Moreover, the System will assess the design process of the maintenance tasks that allocates manpower, competencies, tools, equipment, materials, and parts that are required to execute a work order. Thereafter, the System will proceed to determine the *Total estimated labour hours for ready to work jobs/Actual hours available to schedule each week,* which effectively calculates the backlog of ready-to-work jobs. This dimension is concluded by assessing the 5S tool within the planning department.

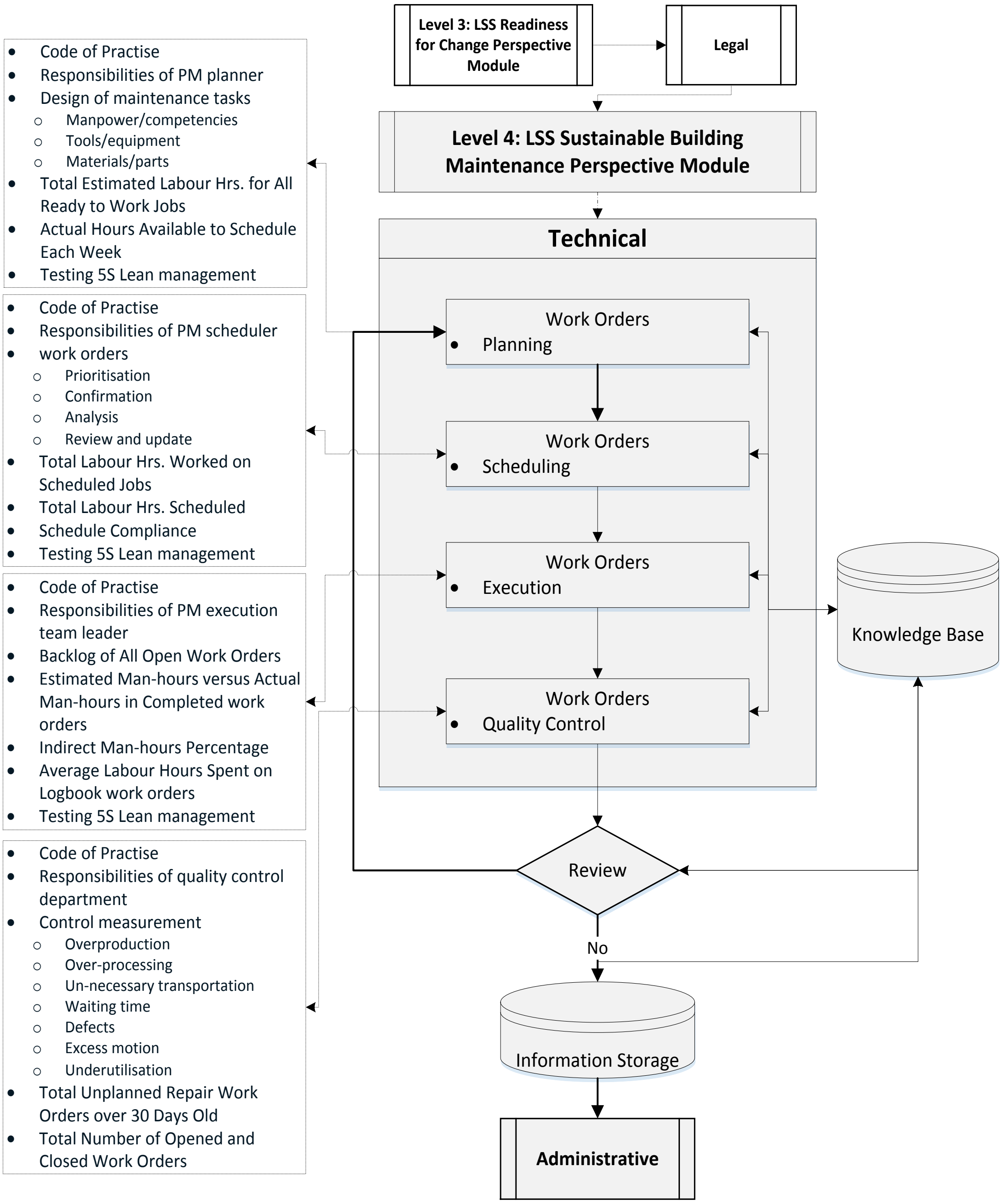


Figure 6. 18 Process Flow Chart of Organisation Technical Sub-Module

The next dimension in this sub-module is the *Scheduling*. The process shows that testing this dimension starts by investigating the concerned responsible department and current certified coded practice (if any). Similar to the *Planning* dimension, the System will proceed further to evaluate the scheduler responsibilities such as identifying the work orders that need scheduling, prioritising the work orders, feedback analysis concerning scheduling issues, and providing ongoing support to the PM planner and PM team leaders. Additionally, the System will confirm that each responsibility has been addressed as per the benchmark standard.

According to Hastings (2015), PM schedules are normally created and approved one week prior to the commencement date. Except for the emergency cases (immediate priority), the schedule contents have to be changed only through an agreement between the operation and the maintenance manager. In essence, the KB System will proceed to determine the percentage of the desired schedule compliance (*Total labour hours worked on scheduled work order/Total labour hours*). Similarly, this dimension is concluded by testing the 5S tool within the scheduling department.

The *Execution* is the following dimension to be assessed. Again, the KB System will identify the availability of the PM section/department responsible to perform the work order tasks' activities. The next step for the System is to ensure that the organisation has allocated a technical team that is dedicated only to PM activities. This team has to be supported by a proper code of practice such as the Chartered Institution of Building Services Engineers (CIBSE) Guide M. Adding to this, the System will verify the responsibilities of the PM team leader and whether he/she is active in implementing them. Such responsibilities include consulting the health and safety engineer to minimise maintenance accidents through risk identification, weekly review of maintenance schedule, execution of work orders according to benchmark standards, and accurate recording of PM history.

The KB System will then examine the performance in the backlog of all open work orders, the backlog of logbook work orders, and direct and indirect labour hours spent on the logbook. This will be followed by the final assessment in the *Execution* dimension where the System evaluates the efficient use of the 5S tool as a pre-requisite of LSS transformation.

The last dimension in the *Technical* sub-module is *Quality Control*. The same process of assessment will take place with respect to the availability of the concerned department, and in allocating an exclusive functional team to conduct quality control activities. The process is continued to investigate the availability of a practised code and the degree of implementing the SBM standard within that code to fulfil legal obligations.

Thereafter, the System will evaluate the department responsibilities and measurement control activities for the most common quality wastes (i.e. over-production, inventory, over-processing, un-necessary transportation, waiting time, defects, excess motion, and under-utilisation). The assessment will be completed by identifying the trends of the unplanned repair work orders and the total number of opened and closed work orders in the last 30 days.

The following set of KB rules are developed within the work order *Execution* dimension in the *Technical* sub-module:

IF *The crew target towards all open PM work orders is (4-6 weeks: GP; <4 weeks: BP-PC-5; >6 weeks: BP-PC-2)*
AND *The estimated man-hours versus actual man-hours for completed PM work orders is (1-16%: GP; 17-30%: BP-PC-5; 31-50%: BP-PC-3; 51-100%: BP-PC-1)*
AND *The indirect man-hours percentage for the PM work orders is (=< 2%: GP; 3-10%: BP-PC-4; 11-20%: BP-PC-3; 21-50%: BP-PC-2; 51-100%: BP-PC-1)*
AND *The average labour hours spent on logbook jobs is (=< 2 labour hours: GP; 3-10 labour hours: BP-PC-4; >=11 labour hours: BP-PC-1)*
THEN *The organisation is good with respect to PM work execution*
OR *The organisation is weak with respect to PM work execution*

The above KB rules are triggering the organisation’s current performance of PM work execution based on the BSI (2007) and NASA (2008). At first, the user will be asked for the period taken by the crew to complete all opened work orders. This aspect becomes critical if more deferred work orders exist or the set target (4–6 weeks) is exceeded. According to NASA (2008), the benchmark percentage of estimated man-hours versus actual man-hours for completed work orders in a specific period is ±15%. The knowledge behind that is to investigate whether the execution team has performed the task required within the estimated man-hours. The System has rated the criticality in this aspect if the ratio percentage exceeds 50%. The next rule to be triggered is the percentage of indirect man-hours allocated for the PM work order. The BSI (2007) described direct labourers as those whom they work in the field, whereas indirect labourers are those who support the technical team (e.g., managers, clercks, planning and scheduling staff, and store keepers). The benchmark standard in this aspect (the percentage of having indirect man-hours for PM work orders) is less than or equal to 2%. In fact, any increase in this percentage will lead to a problematic area that requires further improvement. The last rule in this example determines the average labour hours spent on logbook work orders; in which the KB System benchmark is set at two hours or less with the assumption that the maintenance tasks are well defined and properly scheduled.

6.6.3 Administrative

The purpose of this sub-module is to assess the administrative aspects according to the organisational performance measurements in the SBM environment. The focal point of the assessment is focused on the budget compliance (BC) of the required functional system performance based on PM history and the availability of the waste elimination programme. The organisation needs to assess the efficiency of the management commitment towards BC in conjunction with the financial resources (Kaufman and Balsley, 2009).

The *Administrative* sub-module is developed to assess the current status of managing the maintenance budget based on data history of the maintenance cost in the Lean6-SBM organisation. The assessment includes *Strategic Budget Compliance, Preventive Maintenance Cost Analysis,* and *Operations Budget Compliance* which are presented in the process flow chart (Figure 6.19).

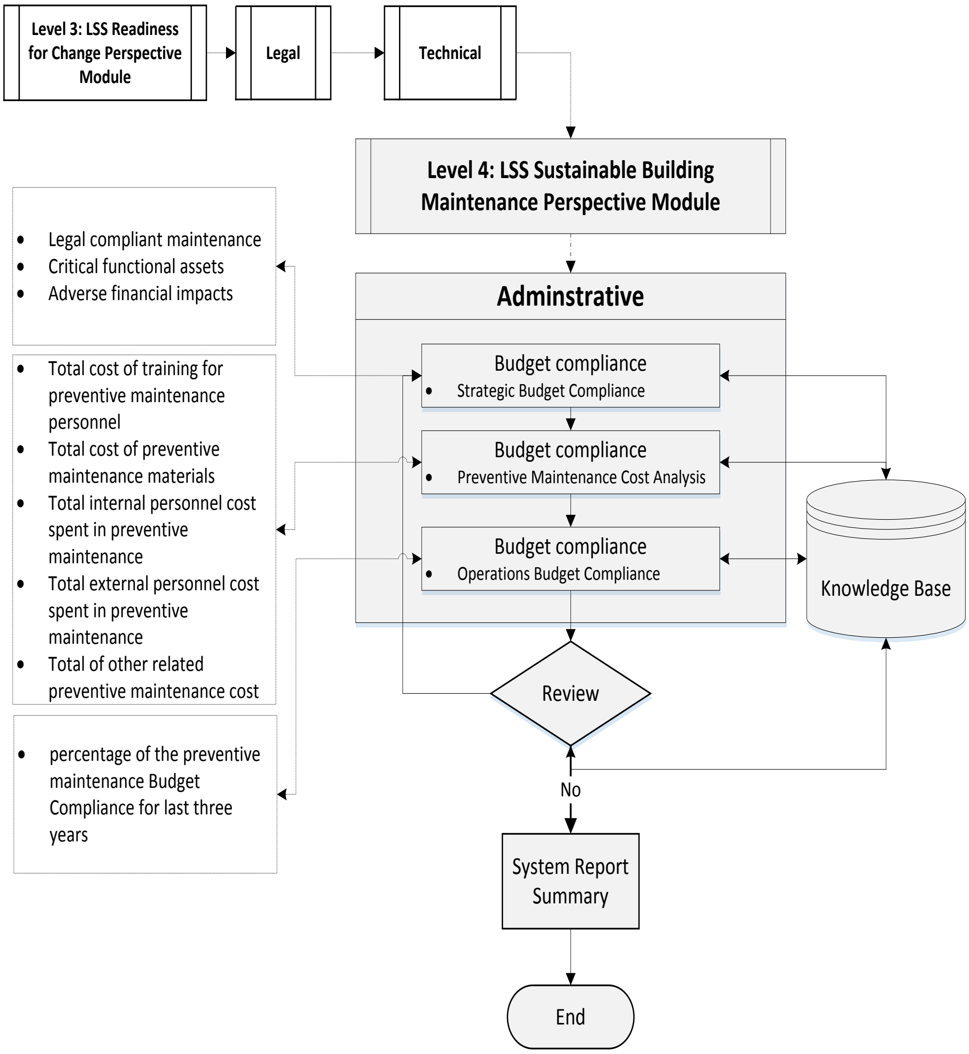


Figure 6. 19 Process Flow Chart of Organisation Administrative Sub-Module

As shown in the figure above, the KB System begins by evaluating strategic issues to make sure that BC is adequate to fulfil the legal PM requirements. The BSI (2013) has placed emphasis on setting an initial maintenance budget that must cope with the minimum requirement of legal compliance in the maintenance strategy. Following that, the System will look to see if the organisation has considered funding the maintenance of critical functional assets. This will drive the System to investigate whether the organisation has worked to avoid adverse financial impact through optimising the investment in functional performance.

The second dimension to be assessed in the *Administrative* sub-module is the BC towards *Preventive Maintenance Cost Analysis*. Jardine and Tsang (2013) declared that in order to reach high maintenance efficiency and productivity, a reasonable investment in new assets and maintenance costs within budget must be achieved. In order to calculate the BC in PM, the KB System will start by examining what types of costs have been considered as part of total PM cost. These should include the cost of internal and external personnel spent for PM, cost of the equipment used for inspection, cost of training for PM personnel, cost of materials/spare parts, cost of miscellaneous items, and the cost of the seven common quality wastes.

The last test in this sub-module is for the dimension of the BC in the operational side. The System will assess the percentage ratio of the BC in the last three years to ensure that a steady state financial control of the PM budget allocation is attained.

The following set of KB rules is created within the *Operations Budget Compliance* dimension in the *Administrative* sub-module:

IF *The organisation has calculated the percentage of the preventive maintenance Budget Compliance in last three years (Yes: GP; No: BP-PC-1)*

AND *The percentage of the preventive maintenance Budget Compliance for last year is ((15-18%): GP; <15%: BP-PC-1; >18%: BP-PC-1)*

AND *The percentage of the preventive maintenance Budget Compliance for 2 years ago is ((15-18%): GP; <15%: BP-PC-1; >18%: BP-PC-1)*

AND *The percentage of the preventive maintenance Budget Compliance for 3 years ago is ((15-18%): GP; <15%: BP-PC-1; >18%: BP-PC-1)*

THEN *The organisation has a steady state PM operation financial control*

OR *The organisation is weak with respect to PM operation financial control*

As the maintenance budget allocation is usually done on an annual basis, it is very important to capture the data of the last three years (at least) in order to create a clear trend for future forecasting. Thus, the absence in the first KB rule will lead to a serious problem (PC-1). According to the BSI (2007), the best practice of the percentage ratio of *Total PM cost/Total maintenance cost* has to be in the range from 15%–18%. Therefore, it can be noted from the second rule that the System will alert a serious problem if the user response goes below/over these limits. This scenario will be conducted similarly for the other two consecutive years.

6.7 Level 5: DMAIC Implementation

The quality perspective will play around the basic philosophy requirements of LSS. According to Zhang et al. (2012), the LSS implementation is accomplished on a project basis in which each project must be completed in a time frame from three to six months. To ensure a successful implementation of this approach, specifically in the field of SBM, the IDEF0 model of DMAIC Implementation perspective is categorised into *Pre-implementation* and *Post-implementation* dimensions as shown in Figure 6.20.

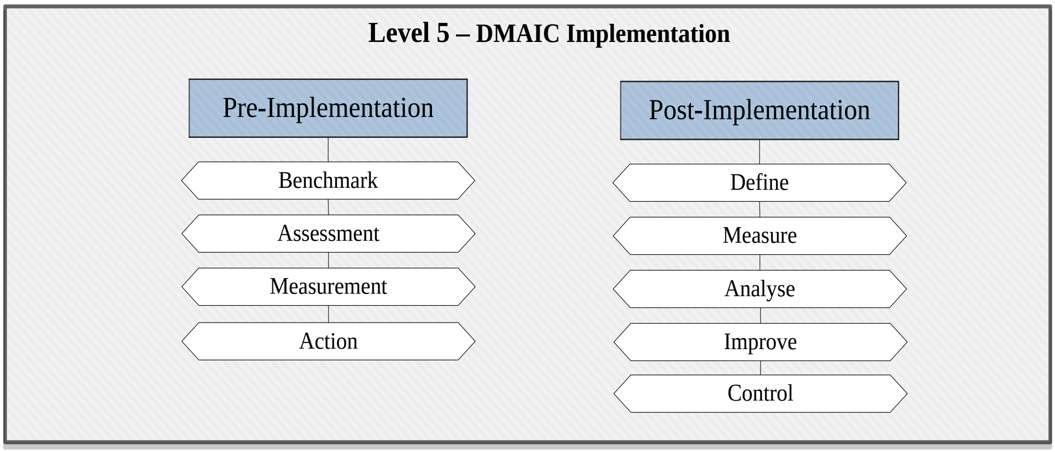


Figure 6. 20 IDEF0 Model of DMAIC Implementation

Basically, *Level 5 DMAIC Implementation* is designed to evaluate the on-going/completed LSS projects conducted by the SBM organisation. Therefore, this Level will help in capturing data about the organisation's readiness before implementing LSS and the degree of success in each phase (within the DMAIC cycle) after the implementation. The rules embedded in the module will create relationships, converting that data into information. By assessing and comparing the level of performance of the organisation with the System benchmark, the module will convert that information into recommendations about the implementation issues of the organisation.

6.7.1 Pre-implementation

George et al. (2003) pointed out that most of the organisations are not structuring their LSS deployment correctly. The other fact refers to the lead time reduction generated from waste. There are seven types of waste in the production and construction environment: delays, defects, excessive people movement, excessive transport, excessive inventory, over-production, and over-processing (Al-Aomar, 2012). On the other hand, Bhatia and Drew (2006) defined the need for customer focus where all of the activities must be tested to ensure they are efficient and they are adding value to the customer. Accordingly, Brown and Lam (2008) proved that customer response is driven by a consistent employee satisfaction which has to be measured continuously.

The reason for developing this sub-module is to ensure that basic pre-requisites of the implemented LSS project have been addressed. The sub-module is divided into four dimensions: *Benchmark, Assessment, Measurement*, and *Action* which are illustrated in the process flow chart (Figure 6.21). The process begins by identifying the organisation benchmark standard with respect to implementing LSS. This should include having a clear vision and level of recognition of LSS, team building strategy, commitment from top level management and the project team members, structured communication plan, and training strategy.

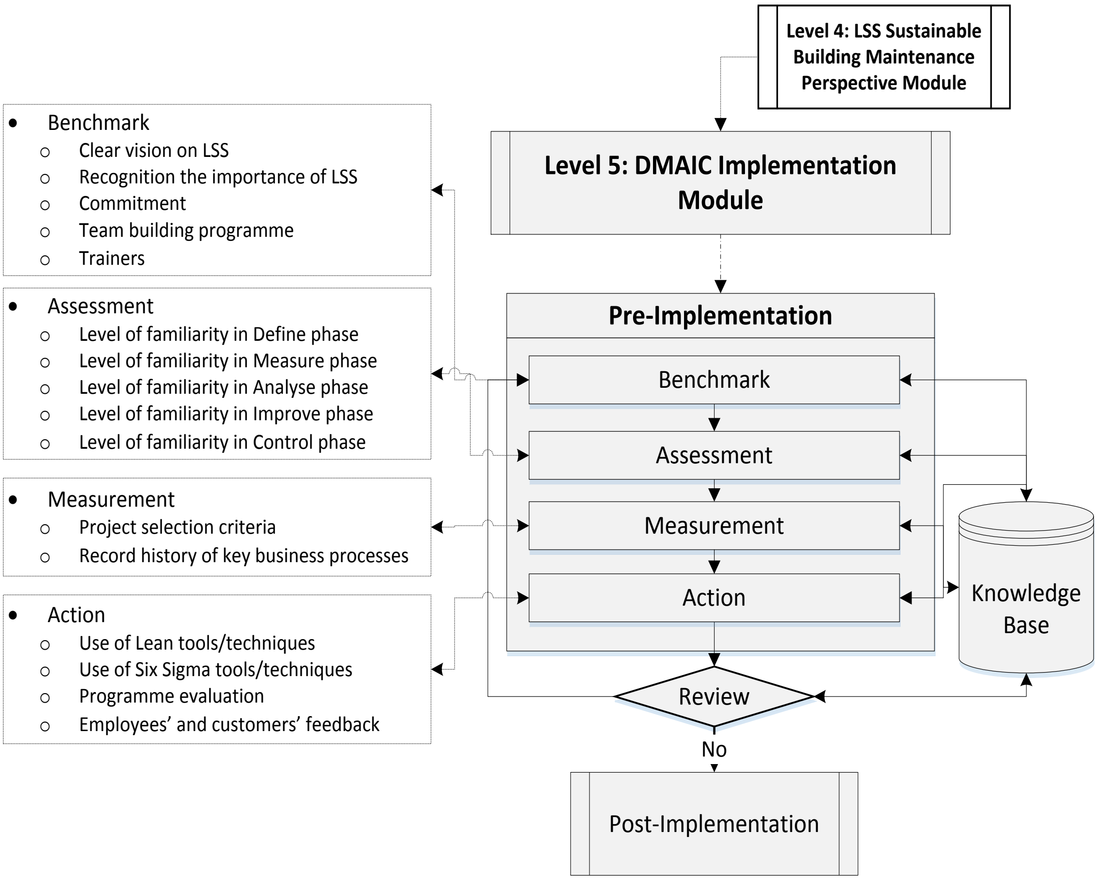


Figure 6. 21 Process Flow Chart of Pre-Implementation Sub-Module

Thereafter, the System will examine the level of familiarity (the dimension of *Assessment*) of team members with regards to implementing the DMAIC phases (i.e., Define, Measure, Analyse, Improve, and Control). This is followed by the dimension of *Measurement*, in which the selection process of the LSS project is assessed based on certain criteria. Snee (2010) has emphasised that the selected LSS project should perform a high value with respect to business goals. Additionally, it should focus on a process that produces pain to the organisation. This will be followed by checking the availability and the ability of creating clear data and recording history of the process variables.

The last part in this sub-module is the dimension of *Action*, in which the KB System aims to evaluate the level of familiarity (of the project team members) in using critical LSS tools/techniques. This is followed by investigating lessons learnt from previous programmes (if any), and the actions taken based on the employees' and customers' feedback to improve the implementation process.

The following set of KB rules is produced within the *Assessment* dimension in the *Pre-implementation* sub-module:

IF *The level of the LSS project team with regards to implementing DMAIC Define phase is*
AND *The level of the LSS project team with regards to implementing DMAIC Measure phase is*
AND *The level of the LSS project team with regards to implementing DMAIC Analyse phase is*
AND *The level of the LSS project team with regards to implementing DMAIC Improve phase is*
AND *The level of the LSS project team with regards to implementing DMAIC Control phase is*
THEN *The organisation's project team was capable to conduct the DMAIC project*
OR *The organisation's project team was in need of more training in DMAIC implementation*

(Very Good: GP; Good: BP-PC-4; Medium: BP-PC-3; Poor: BP-PC-2; Very Poor: BP-PC-1)

The above KB rules trigger the question that investigates whether the organisation's LSS project team was capable of proceeding with implementation of the selected project. In fact, the project manager has to ensure that the whole team is aware of the implementation process. In other words, every member should have the basic knowledge and skills to accomplish each phase of the DMAIC cycle. This will lead to acceleration of the organisation's culture change and achieving a high standard in addressing the project aim and objectives. In this set of rules, the assessment rating has been categorised so that the user response will reveal a critical problem if the answer is 'Poor' or 'Very poor'.

6.7.2 Post-Implementation

This sub-module explains the designed process in assessing an LSS DMAIC project after the implementation takes place. Berardinelli (2012) stated that the DMAIC cycle should be used in a complex or high risk problem. In fact, it is not a process to implement best practices; it is a process to discover best practices.

DMAIC is a data-driven approach that is structured in a way of learning from previous phases. This means that the *Define* phase will help the project team know what to measure; the *Measure* phase will help with what to analyse; *Analyse* will help with what to improve; and finally *Improve* will help with what to control. Souraj et al. (2010) have elaborated the importance in following the DMAIC structure regardless of how deep each phase might be; based on type of improvement.

Thus, for the purpose of assessing the *Post-implementation* sub-module, the process flowchart shown in Figure 6.22 represents the scheme of the created KB rules.

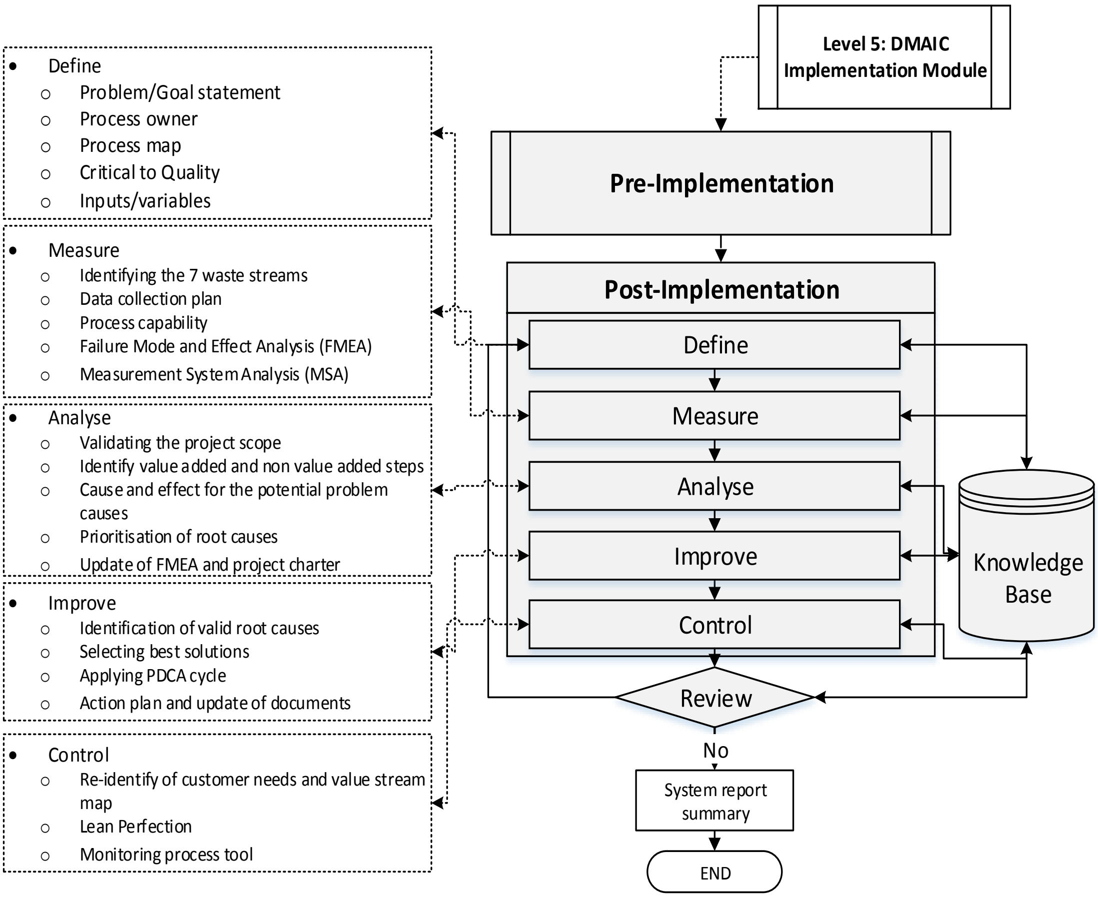


Figure 6. 22 Process Flow Chart of Post-Implementation Sub-Module

From the above diagram, it is obvious that the KB System begins with the *Define* phase, in which the implemented LSS project evaluates whether the main problem and goal statement are identified using a quality method (e.g. COPQ, Pareto Chart). The identification of the problem is the first step in the *Define* phase, followed by defining the expected benefits which need to be achieved (Aldairi et al., 2016). The System will also investigate the process owner, as they have the responsibility for process performance and resources. They provide support, resources, and functional expertise to LSS projects and they are accountable for implementing developed LSS solutions into their process (LSS Black Belt Manual, 2013). Next, the System will investigate the fulfilment of the high level process map, CTQ, and the initial variables. The high level process map can be drawn using VSM or SIPOC (Suppliers, Inputs, Process, Outputs, and Customers) process mapping tools. SIPOC describes not only the high level process steps but also the inputs the process needs and the outputs the process produces (Mishra and Sharma, 2014).

The *Measure* dimension comes next, in which the System will ensure that the organisation has identified the seven waste streams, planned for data collection, measured process capability, created FMEA, and conducted a measurement system analysis (MSA). Many organisations build complex data collection and information management systems without really understanding how the data collected can benefit the organisation (LSS Black Belt Manual, 2013). Moreover, both FMEA (the risk assessment tool to identify potential process) and MSA (which aims to reduce errors through data validation) are crucial to be applied in the *Measure* phase.

The KB System will proceed to evaluate the *Analysis* dimension. In this regard, the LSS project tests whether the initial scope has been validated. Additionally, the System will check if the project team has identified the value added and non-value added steps within the specified process. The System will also look at whether the cause and effect technique was used to determine potential problem causes, and to prioritise those causes. Finally, this dimension will verify whether the FMEA and project charter were updated.

The following part to be evaluated is the dimension of *Improve*. The process starts by identifying the valid root causes derived from the dimension of *Analyse*. This is followed by selecting the best solutions that fit with the Plan, Do, Check, Act (PDCA) continuous improvement cycle, and completed by preparing an action plan and updating the project documents.

The last part in the *Post-implementation* sub-module is the *Control* dimension. The KB System begins the process by ensuring that the project team has re-identified the customer needs, the VSM, and the seven major wastes. Moreover, the System will evaluate actions taken for Lean perfection, and managing the documentation process. Documentation is very important to ensure what has been learned from the LSS projects is systematically shared within the organisation for implementing solutions and supporting on-going training (LSS Black Belt Manual, 2013). Finally, the System will assess the existence of a process monitoring tool (e.g. FMEA, control chart) to secure the objective of continuous improvement. According to Woodall and Montgomery (2014), process monitoring is very important in the *Control* phase. It monitors input variables so that improvement from the previous stage can be maintained over time.

The following example demonstrates a set of KB rules created in the dimension of *Measure*:

IF *The LSS project team has created a current state map of the process related to 'selected process' (Yes: GP; No: BP-PC-1)*

AND *The LSS project team has identified the areas of the 7 waste streams in 'selected process' (Very Good: GP; Good: BP-PC-4; Medium: BP-PC-3; Poor: BP-PC-2; Very Poor: BP-PC-1)*

AND *The LSS project team created a data collection plan for the whole variables need to assessed (Yes: GP; No: BP-PC-1)*

AND *The measurement system of collecting data is accurate and does not cause inherent variation (Very Good: GP; Good: BP-PC-4; Medium: BP-PC-3; Poor: BP-PC-2; Very Poor: BP-PC-1)*

AND *The project metrics have been updated and documented (Yes: GP; No: BP-PC-1)*

AND *The process capability related to 'selected process' has been measured to meet customer expectations (Very Good: GP; Good: BP-PC-4; Medium: BP-PC-3; Poor: BP-PC-2; Very Poor: BP-PC-1)*

AND *The LSS project team has performed the Failure Mode and Effect Analysis (FMEA) for the 'selected process' (Yes: GP; No: BP-PC-1)*

AND *The LSS project team has performed the Measurement System Analysis (MSA) for the 'selected process' (Yes: GP; No: BP-PC-1)*

THEN *The LSS project team has successfully passed the implementation of DMAIC Measure phase*

OR *The LSS project team fails to implement the DMAIC Measure phase*

The above KB rules are triggered to assess the LSS project team in accomplishing the DMAIC *Measure* phase. The KB System begins by asking the user if the project team has created a current state map for the selected process as an output of the *Define* phase. Then, the user will be asked if the team has identified the seven major wastes in the process. The absence in identifying the process wastes is critical at this stage, hence it is categorised as PC-1. Thereafter, the System will investigate if the data collection plan is prepared and actioned accurately. The next step allows the System to ensure that the project variables have been updated and documented. This is followed by ensuring that the measurement of process capability is conducted to meet customer expectations. Antony (2006) has insisted on the importance of using a process capability technique to benchmark the current situation with customer expectations. The last test in this example is concerned with the use of the two most critical tools in LSS (i.e. FMEA and MSA). According to LSS Black Belt Manual (2013), MSA is applicable in 98% of LSS projects. It can have a massive effect on the organisation's success; its main objective is to reduce errors. Due to the complexity of maintenance activities, the absence of applying these two approaches will lead to PC-1.

6.8 Summary

This chapter has described in detail the development of the KB Lean6-SBM System which contains strategic decision levels and operational decision levels. The strategic decision levels were divided into *Level 0: Organisation Environment*, *Level 1: Organisation Business Perspectives*, *Level 2: Organisation Resources Perspective*, and *Level 3: LSS Readiness for Change* modules.

In *Level 0: Organisation Environment* module, two sub-modules were discussed: Organisation Purpose and Strategic Position. These contain general information about the user and the organisation. In the *Level 1* module, two sub-modules have been presented: the *Financial Analysis* where the organisation's financial ratios have to be calculated and benchmarked, and the *Market Analysis* which investigates the market competition and market share in the last three years.

The *Level 2* module has discussed in detail the organisation's resources perspective. It has been categorised into three sub-modules: *Human Resource*, *Technology Resource*, and *Financial Resource*. The *Human* and *Technology Resources* were assessed based on commitment, programmes, and statistics dimensions, whereas the *Financial Resource* was assessed on employees, technology, and implementation.

The *Level 3: LSS Readiness for Change* module represents the last strategic decision level. To ease the process of evaluation, it has been divided into three sub-modules: *ICT, Share Values*, and *Soft TQM*. It was elaborated that the *ICT* sub-module will include assessing the availability of the ICT master plan in addition to the effectiveness of existing legacy systems. On the other hand, the *Share*

Values sub-module will evaluate the aspects of the LSS project manager, cross-functional collaboration, and shared beliefs.

The operational decision levels follow within the development of the KB Lean6-SBM System. In the *Level 4: LSS Sustainable Building Maintenance Perspective* module, the System will incorporate three sub-modules based on SBM taxonomy. These are *Legal*, *Technical*, and *Administrative*. The *Legal* sub-module will be evaluated on contractual attributes, environmental, social, and economic aspects. This will be followed by assessing the *Technical* sub-module with respect to PM work order planning, scheduling, execution, and quality control. Finally, the *Administrative* sub-module will be validated based on strategic budget compliance, preventive maintenance cost analysis, and operations budget compliance.

The last level of the operational decision process is *Level 5: DMAIC Implementation*. In this module, it was decided to include two parts in the assessment: *Pre-implementation* and *Post-implementation*. In the *Pre-implementation* sub-module, the KB System will trigger the organisation’s readiness prior to LSS real implementation. The assessment will be conducted for the dimensions of benchmark, assessment, measurement, and action. Furthermore, the *Post-implementation* sub-module will examine the efficient use of the DMAIC cycle by testing the fulfillment of implementing each phase (i.e. Define, Measure, Analyse, Improve, and Control).

Each of the above mentioned Levels will help to capture the required data. The rules embedded in each module will establish relationships, converting that data into information. By assessing and comparing the level of performance of the organisation, each module will convert that information into recommendations about strategic or operational issues of the organisation (knowledge or know-how).

Chapter 6 has discussed in detail the development process of the KB Lean6-SBM System, which consists of Levels 0, 1, 2, 3, 4, and 5. In Chapter 7, the discussion will be carried out in validating the KB Lean6-SBM model via industrial and published case studies.

Chapter 7

Validation of KB Lean6-SBM Model

7.1 Introduction

This chapter presents the detailed validation processes of the KB Lean6-SBM model. In order to perform these processes, the KB Lean6-SBM model is populated with data from actual industries and published data. The aim is to ensure the model integrity of acquiring and translating the know-how of experts in industry and academia into an explicit form within the model. In addition, the validation of the model also considers the capability of identifying and recommending the areas that need improvements in priority order. According to Min et al. (2010), the validation examines the level of knowledge accuracy embodied in the model to solve a problem; the model represents an analogy of the problem-solving process carried out by experts. In fact, the validation needs subject experts' involvement to have effective knowledge representation and confident assessment of the model (Batarseh and Gonzalez, 2015). This research will follow a similar approach to the validating technique conducted by Mohamed (2012).

As declared in Chapter 1, the novelty of the KB Lean6-SBM model drives up the validation process' simplicity. Therefore, this chapter is focused on the validation and refinement of the KB Lean6-SBM model. To demonstrate the validation process, the chapter presents the validation of the *Financial Analysis* sub-module of *Level 1: Organisation Business Perspective* module through a case study. The case study was taken from the literature, as it provided relevant data to populate the model and demonstrate its benefits. This is due to the availability of the required data from a similar business related annual report. The validation process, which has been conducted in real industries, is basically targeting two groups based on the KB Lean6-SBM model requirements. SBM organisations that have not previously implemented any LSS projects will be assessed from Level 0 to Level 4. On the other hand, organisations, which have previously implemented LSS projects in an SBM environment, will be evaluated for *Level 5* only. In fact, the organisations which are qualified for the assessment of Level 5 will be able to use the first Levels of assessment (i.e. *Level 0–Level 4).*

7.2 Industry Validation Process

The validation process was carried out in three of the facilities management organisations in the Sultanate of Oman. These are the Ministry of Defence Engineering Services – Armed Force Hospital (AFHES), Bahwan Engineering Services (BEC) and the Technical Trading Company (TTC). They have been selected based on their cutting-edge knowledge and application in the field of sustainability and building maintenance (Holding, 2016; BEC, 2017). In addition, AFHES implemented a Lean Six Sigma project in 2014 with inefficient long-term results as stated by their Research and Development Officer *(MODES-HQ)*. Whereas, both BEC and TTC have some initiatives in Lean with no comprehensive review of the expected outcomes as described by the senior engineers involved in the validation process. One further reason behind selecting these organisations, is the ease of access and willingness of research participation during data collection. The validation process for the organisations was done separately in December 2016 at their office headquarters. The validation involved the population of the model considering their strategic plans, and the resources and capabilities relevant to their building maintenance environment. This was followed by comparing the recommendations with their own expert views and opinions. The following briefs describe the facilities management organisations that participated in this validation process.

7.2.1 Bahwan Engineering Services LLC (BEC)

Bahwan Engineering Company LLC (BEC) was established in 1977 as part of the Suhail Bahwan Group. The Group has become a multi-billion pound corporate enterprise with more than 17,000 employees distributed among 40 companies that operate across Oman and other Gulf countries, South Asia, and North Africa. BEC is one of the largest facilities management and maintenance providers in Oman and the UAE. Currently, BEC is operating in more than 3,240 locations with the number of contracts exceeding 710 over the two countries. Its overall market share in the last three years is around 20%, with annual turnover of £20 million and the number of employees exceeding 2,280 in 2016 (BEC, 2016).

The company is leading in most buildings maintenance activities (e.g. HVAC systems, firefighting systems, and MEP (mechanical, electrical, and plumbing) systems. The Company adheres to international work standards in ISO 9001:2008 quality management systems requirements, ISO 14001:2004 environmental management system, and OHSAS 18001:2007 occupational health and safety.

The developed KB Lean6-SBM model was validated by Deputy General Manager, Mr N. Ramesh Babu, and Senior Service Engineer, Mr K. Sujith Rao. Both are considered to be experts in the facilities management and maintenance field within BEC. They validated all Levels (*Level 0–Level 4*) of the KB Lean6-SBM model, however, they declined to validate the *Financial* sub-module in the *Level 1: Organisation Business Perspective* module for the reason of business confidentiality. Because of that, it has been decided to validate the *Financial* sub-module separately using a published case study (Servest Group Limited annual report).

7.2.2 Technical Trading Company (TTC)

The Technical Trading Company (TTC) was established in 1970 and became a part of Al Sulaimi Group Holding at a later stage. The Group is operating in three countries: Oman, UAE, and Saudi Arabia with a total of 11 active companies and more than 3,000 employees. The annual group turnover is approximately £60 million. TTC started its service facilities in Muscat with gradual expansion throughout the country (Oman). It has a constant performance in overall market share in the last three years (10% in average), with last year’s turnover of £5 million and the number of in-house employees exceeding 130 (Holding, 2016).

TTC has led innovations in various sectors of the facilities management area. They specialise in measuring design requirements, installation, and maintenance of different elevators and escalators. TTC is also taking the lead in MEP systems. The company has been certified to ISO 9001:2008 by the Guardian Independent under the accreditation of UKAS (United Kingdom Accreditation Service).

The developed KB Lean6-SBM model was validated by the Operations Manager, Mr K. Sanath and Quality Engineer, Mr Cromwell. Both are considered to be experts in the building maintenance division within TTC. They validated all

Levels (*Level 0–Level 4*) of the KB Lean6-SBM model, however, as explained in the previous section of this chapter, the *Financial* sub-module was populated and validated using the case study of the Servest Group Limited’s annual report.

7.2.3 Armed Force Hospital Engineering Services (AFHES)

The Armed Force Hospital Engineering Services (AFHES) is a facilities management and maintenance unit within the establishment of the Ministry of Defence Engineering Services (MODES) that is controlled by the Office of the Secretary General (MoD – Oman). MODES is a non-profit organisation accountable for providing services of energy, water, and public health to all camps of the MoD (Oman), along with all kinds of infrastructure maintenance in those public camps. In addition to this, MODES is involved in initiation, planning, delivering, monitoring, and closure of all types of construction projects within MoD – Oman (MODES-HQ, 2016).

MODES is divided into 14 major directorates; each directorate is tasked to provide certain facilities based on the capacity of the services required, the importance of the infrastructure, and the geographical area of the unit (a location/camp within a directorate). The overall staff of the organisation is approximately just over 6,000 people with annual turnover exceeding £[∗] million (MODES-HQ, 2016).

AFHES is a unit within Muscat Directorate which has the responsibility for the maintenance of all the buildings’ services related to the hospital. The annual turnover of this unit is £[∗] with a total of 160 employees working under the establishment (SUS-AFHES, 2017). These are distributed among five main/key departments: *Electrical*, *Mechanical*, *Civil*, *Logistics,* and *Administration*.

Three years back, AFHES carried out the implementation of an LSS project to resolve a problem of frequent failures in sewage treatment pumps located in the hospital sewage treatment plant. Despite the initial project success, the same problem has been noticed recently in some other MODES locations including AFHES. Therefore, they have participated in validation of the *Level 5: DMAIC Implementation* module based on that project’s implementation failure. The module

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[∗] The financial figures given for MODES and AFHES are strictly confidential was validated by the Senior Unit Superintendent, Mr Suliman Al Busaidi. He has 25 years' extensive experience in facilities management and maintenance services.

Table 7. 1 Summary of BEC, TTC, AFHES, and Related Groups

	Suhail Bahwan Group	**BEC**	**Al Sulaimi Group**	**TTC**	**MODES**	**AFHES**
Turnover **(estimated)	>£3 billion**	£20 million	£60 million**	£5 million	£*	£*
Number of Employees	17,000	2,280	3,000	130	>6000	160
Lean6-SBM Level	-	Level 0-4	-	Level 0-4	-	Level 5

Table 7.1 illustrates a summary of the three organisations (with their belonging Groups) involved in KB Lean6-SBM validation and validation processes, based on their turnover, number of employees, and the system Levels.

7.3 Validation of KB Lean6-SBM Model Based on the Industry Data

The KB Lean6-SBM model consists of five decision-making Levels: the first one is a pre-requisite perspective (*Level 0: Organisation Environment* module) followed by *Level 1* to *Level 4*. Moreover, a separate implementation level (*Level 5: DMAIC Implementation* module) has been designed as shown in the reprinted conceptual framework of Figure 5.5, Chapter 5. For *Level 0 to Level 4*, the process of validation was carried out with BEC and TTC. In fact, they were not able to participate in the validation of *Level 5* as they have not implemented any LSS projects so far. The same validation process was carried out for *Level 5* in AFHES, as they have previously conducted an LSS project. The detailed inputs, outputs, and analysis of BEC and AFHES are used in this chapter to show the KB Lean6-SBM capability during the process of validating the modules. The TTC analysis results are presented at the end of the chapter as a summary, while the detailed inputs and outputs are shown in Appendix B. Therefore, Sections 7.3 to 7.4 are the KB Lean6-SBM results and discussion of organisation BEC, Section 7.5 presents the results' summary and discussion of organisation TTC, and finally, Sections 7.6 and 7.7 presents the results and discussion of organisation AFHES.

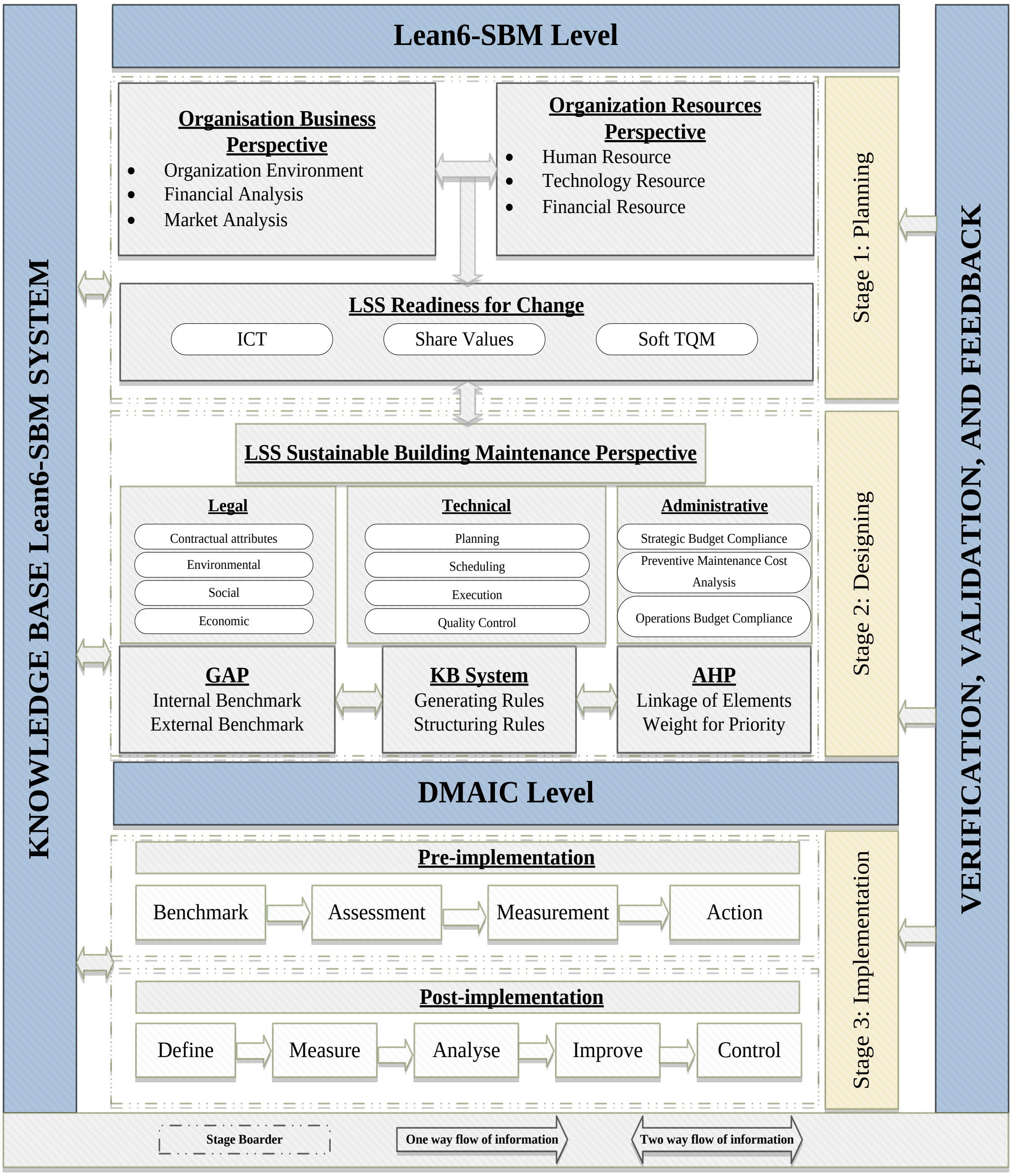


Figure 5.5 KB Lean6-SBM Conceptual Framework (Reprinted from Chapter 5)

7.3.1 Organisation BEC: Level 0 – Organisation Environment

This section will show how the *Organisation Environment* Level (Figure 7.1) will help in capturing data about the environment of the BEC and its performance. It will show how the rules embedded in the module will establish relationships, converting that data into information. By assessing or comparing the level of performance of BEC, the module will convert that information into recommendations about strategic issues of the company (knowledge or know-how).

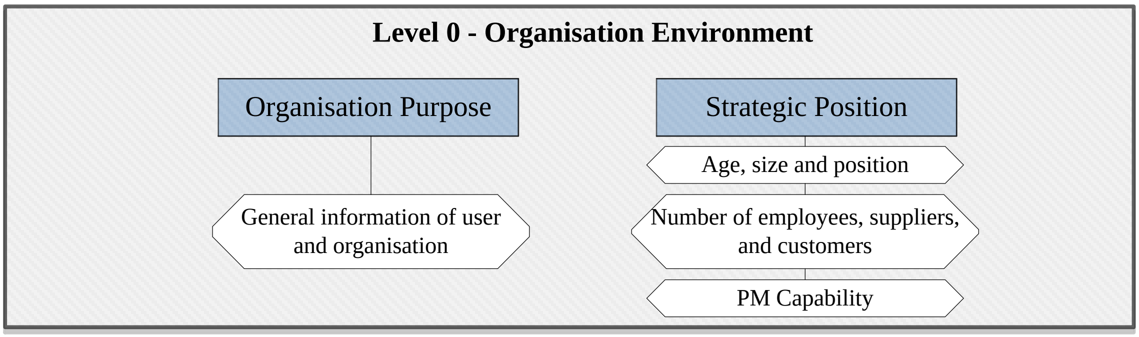
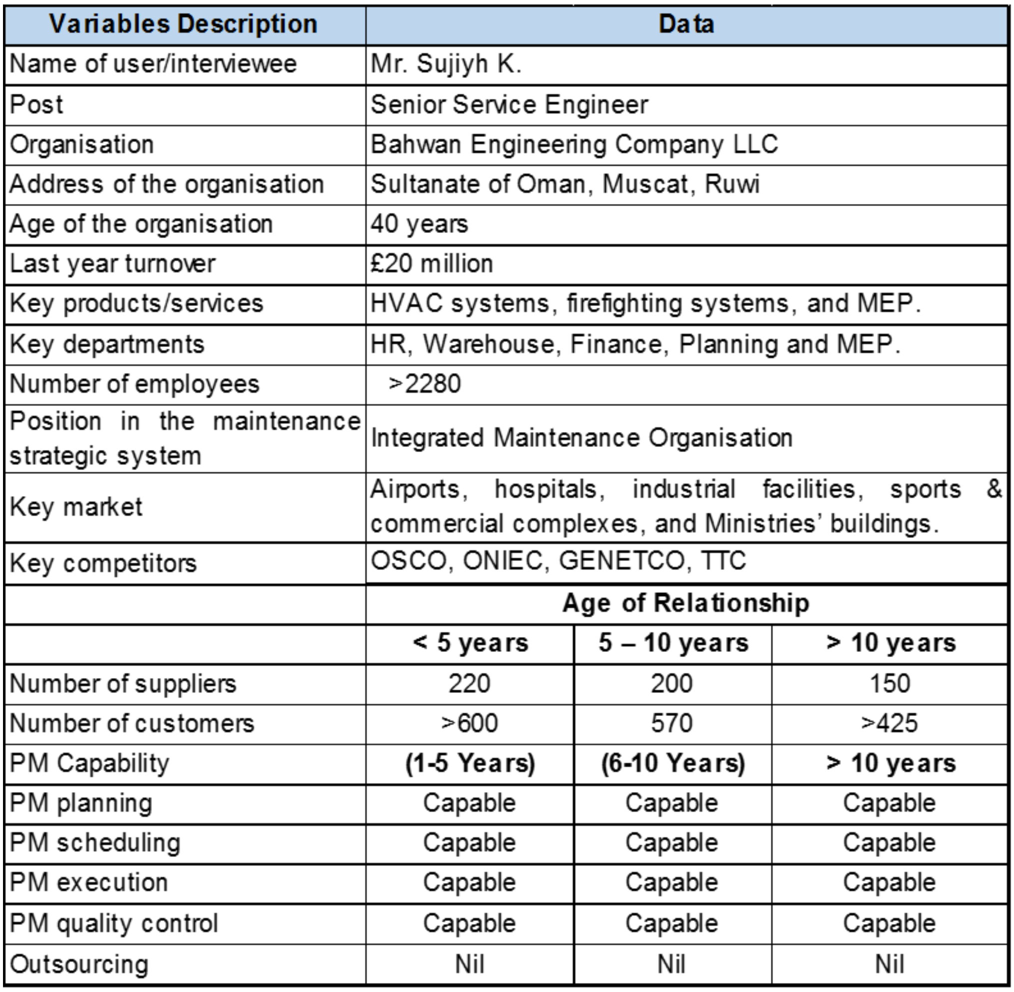


Figure 7. 1 Organisation BEC: Level 0 - Organisation Environment Perspective

Level 0 of the KB Lean6-SBM model requires the user to provide some basic information as shown in Table 7.2.

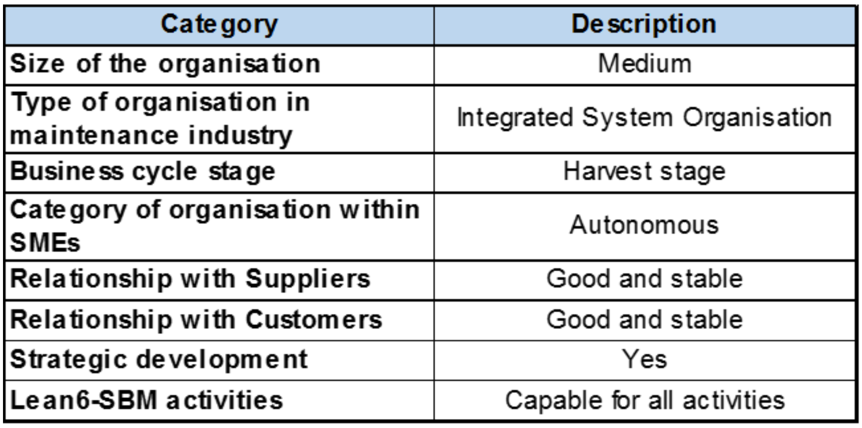
Table 7. 2 Organisation BEC: Inputs of Organisation Environment



Variables Description	Data		
Name of user/interviewee	Mr. Sujiyh K.		
Post	Senior Service Engineer		
Organisation	Bahwan Engineering Company LLC		
Address of the organisation	Sultanate of Oman, Muscat, Ruwi		
Age of the organisation	40 years		
Last year turnover	£20 million		
Key products/services	HVAC systems, firefighting systems, and MEP.		
Key departments	HR, Warehouse, Finance, Planning and MEP.		
Number of employees	>2280		
Position in the maintenance strategic system	Integrated Maintenance Organisation		
Key market	Airports, hospitals, industrial facilities, sports & commercial complexes, and Ministries' buildings.		
Key competitors	OSCO, ONIEC, GENETCO, TTC		
	Age of Relationship		
	< 5 years	**5 – 10 years**	**> 10 years**
Number of suppliers	220	200	150
Number of customers	>600	570	>425
PM Capability	**(1-5 Years)**	**(6-10 Years)**	**> 10 years**
PM planning	Capable	Capable	Capable
PM scheduling	Capable	Capable	Capable
PM execution	Capable	Capable	Capable
PM quality control	Capable	Capable	Capable
Outsourcing	Nil	Nil	Nil

Subsequently, the analysis of the information in the KB Lean6-SBM has produced the output as tabulated in Table 7.3.

Table 7. 3 Organisation BEC: Output Results of Level 0: Organisation Environment Perspective Module



Category	Description
Size of the organisation	Medium
Type of organisation in maintenance industry	Integrated System Organisation
Business cycle stage	Harvest stage
Category of organisation within SMEs	Autonomous
Relationship with Suppliers	Good and stable
Relationship with Customers	Good and stable
Strategic development	Yes
Lean6-SBM activities	Capable for all activities

Based on the general data captured from the user (i.e. age, size, position, number of employees, number of suppliers, number of customers, number of competitors, and capabilities in PM activities), the KB Lean6-SBM model was able to determine the purpose and current strategic position of BEC. According to that information, the KB Lean6-SBM model has categorised BEC as a medium-sized organisation (based on European SME classification). However, the company is large if the turnover figure is given with respect to the Bahwan Group of companies rather than BEC as a stand-alone organisation. The company is in the *harvest* stage of the business cycle and has good and stable relationships with customers and suppliers. Strategically, it has taken steps to train its workforce by opening a training centre and establishing in-house vendor development based on quality, health and safety environment, pricing, and delivery. From a technical perspective, BEC is capable of the PM planning, scheduling, executing, and quality control.

In summary, for Level 0, the KB Lean6-SBM model requires the organisation's general information as the input. Based on the information obtained, the analysis has produced a competitive output, which reflects the organisation, in terms of size, business cycle stage, relationships with customers and suppliers, and the capability in achieving standards of PM activities.

7.3.2 Organisation BEC: Level 1 – Organisation Business Perspective

Following the *Organisation Environment* Level, the KB Lean6-SBM model has to validate *Level 1: Organisation Business Perspective*. This Level helps in capturing data about BEC's financial statements, and about the company's market analysis in the last three years. The rules developed in the module will establish relationships, converting that data into information. By comparing the level of performance of the BEC with the system benchmark, the module will convert that information into recommendations about which aspects need to be improved in order of priority. This Level is divided into financial and market analysis as shown in Figure 7.2.

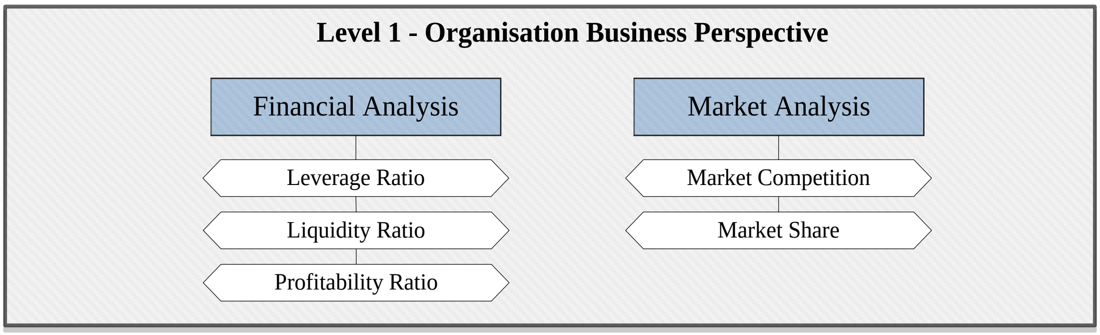
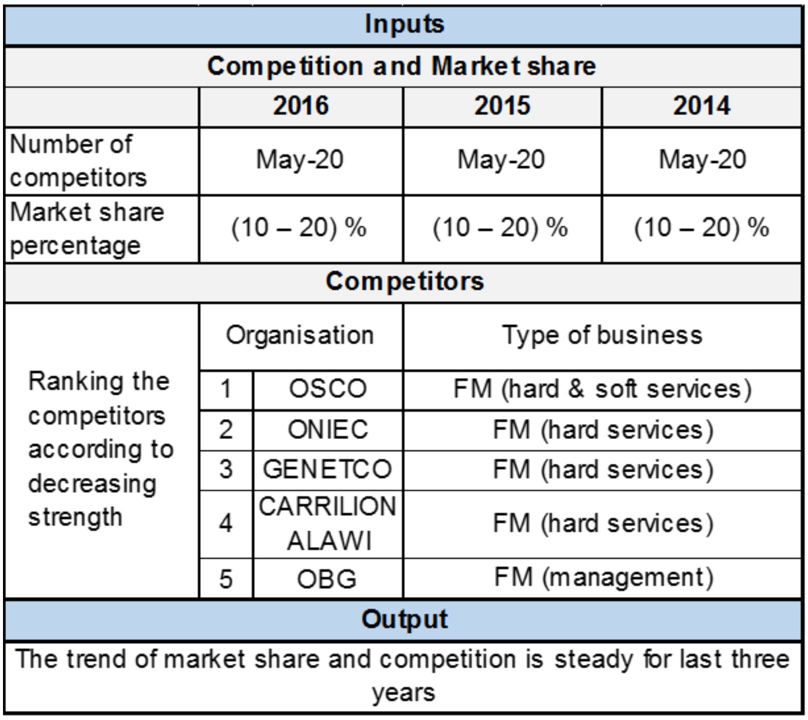


Figure 7. 2 Organisation BEC: Level 1 - Organisation Business Perspective

In order for the KB Lean6-SBM to launch the organisation's financial analysis sub-module, financial statements (i.e. income statement, balance sheet and cash flow) have to exist. According to Ramnath et al. (2008), organisations' financial reports contain all relevant financial information and must be presented based on approved legal and commercial standardisation. In practice, and because of business confidentiality, most of the annual financial reports are available/published only for organisations listed in the financial authority market of a certain country, hence, it was not possible to get the annual financial reports of BEC and TTC, and therefore to assess their financial performance. However, the user in BEC has responded to the KB rules related to the previous year's turnover, which exceeds £20 million, and the market share in the last three years which fluctuates between 10–20%.

The next sub-module in the KB Lean6-SBM *Organisation Business Perspective* is *Market Analysis*. The intent is to get information about the market competition in the field of sustainable building maintenance. This analysis is important for BEC as it could redirect the strategy for future improvements. The inputs and outputs results of the sub-module of the BEC market competition and market share are illustrated in Table 7.4.

Table 7. 4 Organisation BEC: inputs and output results of Market Analysis Sub-module



Inputs			
Competition and Market share			
	2016	**2015**	**2014**
Number of competitors	May-20	May-20	May-20
Market share percentage	(10 – 20) %	(10 – 20) %	(10 – 20) %
Competitors			
Ranking the competitors according to decreasing strength	Organisation		Type of business
	1	OSCO	FM (hard & soft services)
	2	ONIEC	FM (hard services)
	3	GENETCO	FM (hard services)
	4	CARRILION ALAWI	FM (hard services)
	5	OBG	FM (management)
Output			
The trend of market share and competition is steady for last three years			

Based on the inputs from the user, BEC has managed to secure an average of 15% of the local market share in the last three years (2014–2016). The trend shows a steady figure of market share due to an increase in competitiveness that needs to be considered in future strategic development. This might be achieved by focusing more on customer needs by improving the quality of internal processes by applying *CTQ* or *QFD* techniques in order to get the lead on market competitiveness.

In summary, Level 1 of the KB Lean6-SBM model for BEC was not analysed in terms of financial aspects as no information was provided, whereas from the market share perspective it has shown a constant market share over the last three years. This gives an indication that BEC should consider further improvements that could enhance customer loyalty and achieve the required competitive advantages.

7.3.3 Organisation BEC: Level 2 – Organisation Resources Perspective

This section will show how the *Level 2: Organisation Resources Perspective* contributes to capture data about BEC's human, technology, and financial resources and about the BEC's performance in these aspects. The rules embedded in the module will demonstrate relationships, converting that data into information. By comparing the level of performance of BEC with the system benchmark, the module will convert that information into recommendations about strategic problems of the organisation's resources (knowledge or know-how).

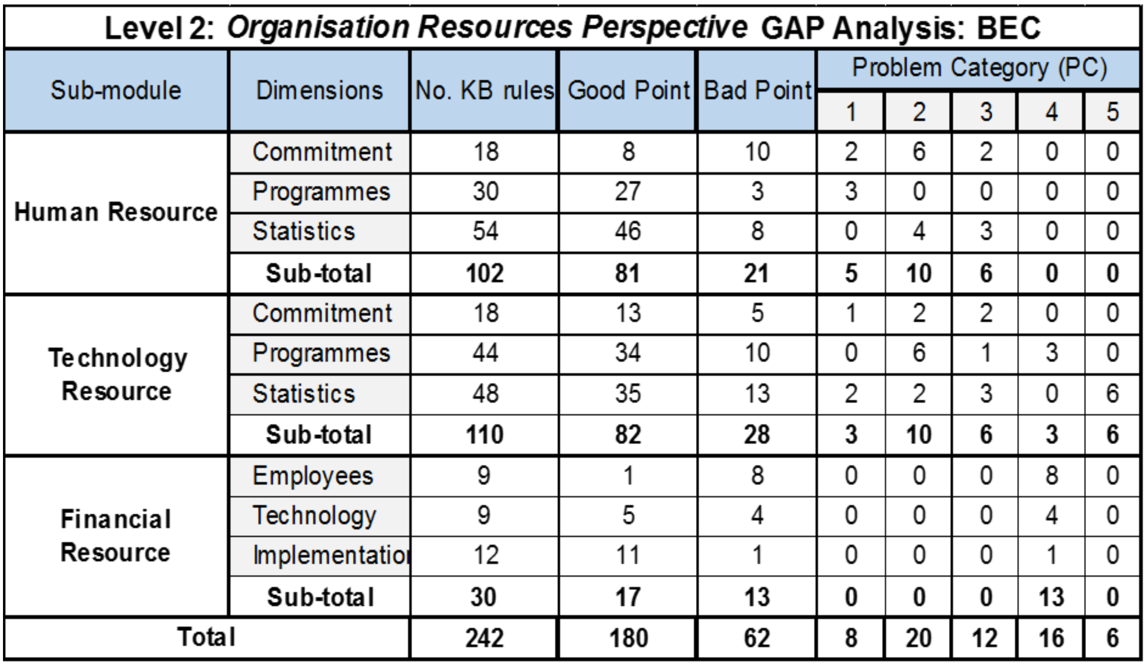
The *Level 2: Organisation Resources Perspective* of the Lean6-SBM model consists of three sub-modules: *Human Resource*, *Technology Resource*, and *Financial Resource* as shown in Figure 7.3. In Lean6-SBM *Organisation Resources*, the KB System evaluates the capability of the key resources of the organisation in dealing with the transformation into an LSS environment.

Figure 7. 3 Organisation BEC: Level - 2 Organisation Resources Perspective

As described in Chapter 6, the *Human Resource* and *Technology Resource* sub-modules contain three similar dimensions under each to be assessed. These include *Commitment*, *Programmes*, and *Statistics*. However, each of the sub-modules is assessed from its own perspectives. In *Financial Resource*, the organisation has to be evaluated from the dimensions of budget allocated to *Employees*, *Technology*, and *Implementation*. This module contains a total of 242 KB rules that have been developed for the knowledge base.

Based on the answers from the user of BEC, the GAP analysis results of the *Level 2: Organisation Resources Perspective* can be summarised as tabulated in Table 7.5. These results reflect the difference between the existing practice and the benchmarked practice. There have been a total of 242 KB rules triggered in this module which include the number of good points (GPs), and the number of bad points (BPs) rated as problem categories (PCs) from PC-1 to PC-5. The optimisation technique (GAP analysis) in this research suggests that only the BPs are categorised as PC in order to find out the necessary pre-requisites for further improvements. Out of 242 KB rules triggered, the system has categorised 180 as GPs and the remaining 62 as BPs. The 62 bad points are classified into different problem categories (8 PC-1, 20 PC-2, 12 PC-3, 16 PC-4, and 6 PC-5) where they represent the activities that need to be improved to achieve Lean6-SBM implementation.

Table 7. 5 GAP analysis results of the Organisation BEC Level 2 - Organisation Resources Perspective



Level 2: *Organisation Resources Perspective* GAP Analysis: BEC

Sub-module	Dimensions	No. KB rules	Good Point	Bad Point	Problem Category (PC)				
					1	2	3	4	5
Human Resource	Commitment	18	8	10	2	6	2	0	0
	Programmes	30	27	3	3	0	0	0	0
	Statistics	54	46	8	0	4	3	0	0
	Sub-total	**102**	**81**	**21**	**5**	**10**	**6**	**0**	**0**
Technology Resource	Commitment	18	13	5	1	2	2	0	0
	Programmes	44	34	10	0	6	1	3	0
	Statistics	48	35	13	2	2	3	0	6
	Sub-total	**110**	**82**	**28**	**3**	**10**	**6**	**3**	**6**
Financial Resource	Employees	9	1	8	0	0	0	8	0
	Technology	9	5	4	0	0	0	4	0
	Implementatio	12	11	1	0	0	0	1	0
	Sub-total	**30**	**17**	**13**	**0**	**0**	**0**	**13**	**0**
Total		**242**	**180**	**62**	**8**	**20**	**12**	**16**	**6**

In the *Human Resource* sub-module, a total of 102 KB rules were triggered of which 81 were GPs (meaning that the pre-requisites for these were met). However, there were 21 KB rules, which were not met (BPs), indicating a gap in pre-requisites for achieving benchmark. A further analysis of these BPs shows that major key BPs were in the dimensions of *Commitment,* and *Statistics*. A key aspect from this analysis is that in the *Commitment* dimension (10 BPs, of which 2 PC-1 and 6 PC-2) which, for leadership, is an extremely important factor that will reflect negatively on building a manageable culture. It is notable that BEC only allows top level management in developing its HRD programmes and determines the required budget and related performance indicators. The impact of paying no attention to the involvement of middle and lower level management in decision making will definitely cascade to other dimensions in the KB Lean6-SBM model. Thus, BEC has to focus on rectifying the problems from category 2 PC-1 before fixing the other 8 PCs (6 PC-2, and 2 PC-3).

In the *Technology Resource* sub-module, a total of 112 KB rules were triggered of which 82 were GPs. However, there were 28 KB rules, which were not met (BPs), indicating a gap in pre-requisites for achieving benchmark. Further analysis of these BPs shows that key BPs were in the dimensions of *Statistics*, and *Programmes*. A critical aspect from this analysis is that in the *Statistics* dimension there were 13 BPs (of which 2 PC-1 and 2 PC-2), in which for technology improvement, the employee participation is a crucial aspect. The KB rules indicate that most of the ideas suggested by the employees were not discussed, which in consequence might lead to break the overall workforce loyalty, and weaken the trust between different managerial levels.

Lastly, for the *Financial Resource* sub-module, out of 30 KB rules triggered, there were 17 GPs and 13 BPs. A further analysis of these BPs shows an unserious problematic area in the *Employees* dimension (13 PC-4). These BPs exist due to the lack of budget allocated for salaries and benefits in addition to the organisation's investment slackening in staff training and career development; both of which are key aspects for building employees' satisfaction, although the KB Lean6-SBM has proven that BEC is not practising a major problem with these aspects.

The above GAP analysis has been used by the KB Lean6-SBM model to produce the AHP analysis. This step is very important as it determines which aspects should be prioritised for further improvements. The integrated AHP will start the analysis by determining the values of priority vectors (PV) in each sub-module. For the sub-modules *Human Resource*, *Technology Resource*, and *Financial Resource*, the PV values of each dimension have been calculated as represented in Tables 7.6, 7.7, and 7.8 respectively.

Table 7. 6 Human Resource AHP analysis with PV for Organisation BEC

Human Resource	Commitment	Programmes	Statistics	P.V
Commitment	1	4	4	**0.66**
Programmes	1/4	1	2	0.21
Statistics	1/4	1/2	1	0.13

Table 7.6 shows the PV values in the *Human Resource* sub-module. The values are **0.66** for *Commitment*, 0.21 for *Programmes*, and 0.13 for *Statistics*. This

means that focusing on this sub-module, BEC's priority is to rectify the dimension of *Commitment* before attempting the dimensions of *Programmes* and *Statistics.* The analysis has indicated a very serious problem in the involvement of middle and lower level management in decisions taken for HRD development.

Table 7. 7 Technology Resource AHP analysis with PV for Organisation BEC

Technology Resource	Commitment	Programmes	Statistics	P.V
Commitment	1	1/2	1/2	0.20
Programmes	2	1	1/2	0.31
Statistics	2	2	1	**0.49**

Table 7.7 indicates the PV values for the *Technology Resource* sub-module. The PV values for *Commitment*, *Programmes*, and *Statistics* are 0.20, 0.31, and **0.49** respectively. Therefore, the priority for BEC to focus on in this sub-module is to improve the dimension *Statistics* (the analysis highlighted that employees' participation is the major issue that needs to be tackled) before attempting the dimensions of *Commitment* and *Programmes.*

Table 7. 8 Financial Resource AHP analysis with PV for Organisation BEC

Financial Resource	Employees	Technology	Implementation	P.V
Employees	1	3	4	**0.62**
Technology	1/3	1	2	0.24
Implementation	1/4	1/2	1	0.14

Table 7.8 indicates the PV values for the *Financial Resource* sub-module. The PV values for *Employees*, *Technology*, and *Implementation* are **0.62**, 0.24, and 0.14 respectively. Therefore, the priority for BEC to focus on in this sub-module is to improve the dimension *Employees* (this was highlighted due to the lack of the annual budget allocated to improve career development and training) before attempting the dimensions *Commitment* and *Programmes.*

The next evaluation is to use the same AHP analysis process to determine the PV values at the sub-modules stage of *Human Resource*, *Technology Resource*, and *Financial Resource*. The summary of these sub-modules' PV values is presented in Table 7.9. The values are **0.49** for *Human Resource*, 0.31 for *Technology Resource*, and 0.20 for *Financial Resource*. This means that by focusing on this module, BEC's priority is to rectify the sub-module of *Human Resource* followed by the sub-module *Technology Resource* and finally the sub-module *Financial Resource.* Similar performance assessment procedures have been conducted for Level 3, and Level 4. The assessment results for TTC are shown in Appendix B.

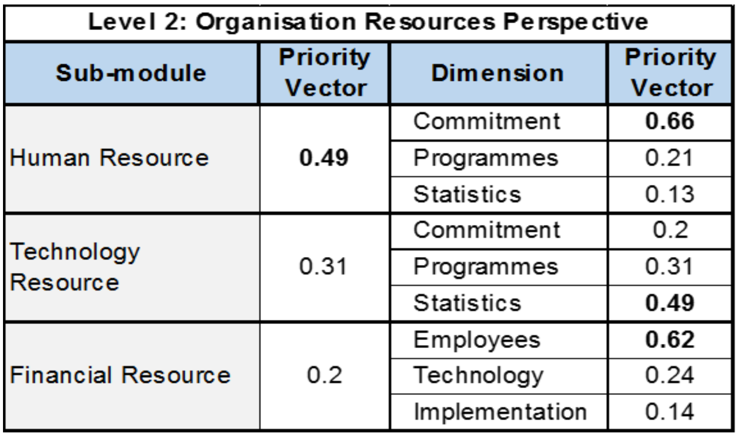
Table 7. 9 Organisation Resources Perspective AHP analysis with PV for Organisation BEC

Level 2	Human Resource	Technology Resource	Financial Resource	P.V
Human Resource	1	2	2	**0.49**
Technology Resource	1/2	1	2	0.31
Financial Resource	1/2	1/2	1	0.20

Table 7.10 summarises the AHP-PV values for each of the dimensions and sub-modules for the *Organisation Resources Perspective* module. Thus, the KB Lean6-SBM AHP has assisted the management to prioritise the improvement, showing what needs to be done in a descending order. The KB Lean6-SBM analysis proposes that BEC should centre their efforts firstly to resolve the area of *Human Resource* due to the highest PV of 0.49. The KB Lean6-SBM also requires BEC to improve the *Commitment* dimension which has a PV of 0.66. The KB Lean6-SBM analysis recommends that BEC should then focus on the *Technology Resource* sub-module (PV = 0.31) before proceeding to improve *Financial Resource*. In the *Technology Resource,* more attention has to be given to the

Statistics dimension that has a PV of 0.49, whereas in the *Financial Resource* sub-module, BEC needs to be concentrated on the *Employees* dimension (PV = **0.62**).

Table 7. 10 Summary of AHP PV values for Level 2 - Organisation Resources Perspective for Organisation BEC



Level 2: Organisation Resources Perspective			
Sub-module	**Priority Vector**	**Dimension**	**Priority Vector**
Human Resource	**0.49**	Commitment	**0.66**
		Programmes	0.21
		Statistics	0.13
Technology Resource	0.31	Commitment	0.2
		Programmes	0.31
		Statistics	**0.49**
Financial Resource	0.2	Employees	**0.62**
		Technology	0.24
		Implementation	0.14

In summary, for Level 2, the KB Lean6-SBM model analysis has recorded the GAP analysis of 62 BPs from 242 KB rules triggered. This revealed that BEC is 25.62% below the benchmark standard in measuring resources capability to implement LSS. Therefore, in order to achieve a Lean6-SBM environment, BEC has to improve the *Commitment* dimension in the *Human Resource* sub-module.

7.3.4 Organisation BEC: Level 3 – LSS Readiness for Change

The *Level 3: LSS Readiness for Change* of the Lean6-SBM model consists of three sub-modules: *ICT*, *Share Values*, and *Soft TQM* as shown in Figure 7.4. Level 3 assists in capturing data about BEC's ICT development, share values, and about BEC's TQM achievements. The rules embedded in the module will validate relationships, converting that data into information. By assessing and comparing the level of performance of BEC with the system benchmark, the module will convert that information into recommendations about strategic issues related to readiness for change. In *LSS Readiness for Change*, the KB System measures the readiness of the organisation in dealing with the transformation into an LSS environment.

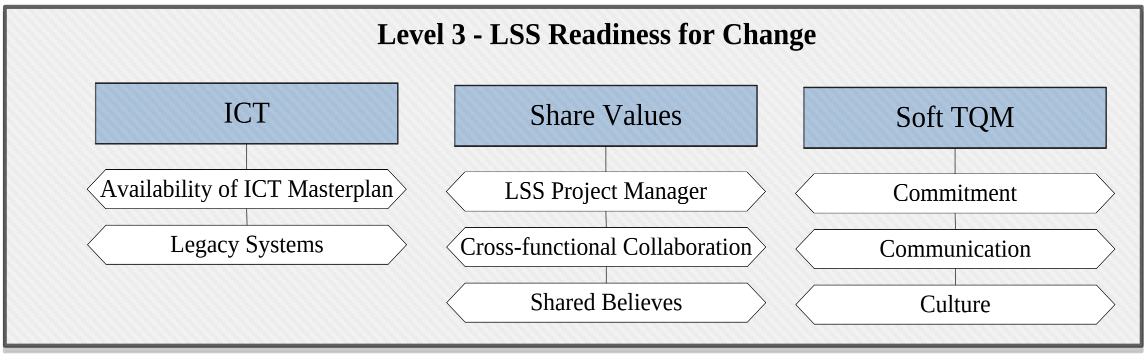


Figure 7. 4 Organisation BEC: Level 3 - LSS Readiness for Change

As described in Chapter 6, the *ICT* sub-module will be assessed based on two dimensions: *Availability of ICT Masterplan* and *Legacy Systems*, whereas the *Share Values* sub-module will cover the areas of *LSS Project Manager*, *Cross-functional Collaboration*, and *Shared Beliefs*. On the other hand, the *Soft TQM* sub-module contains three dimensions to be assessed which include: *Commitment*, *Communication*, and *Culture*.

Table 7.11 summarised the BEC GAP analysis results of the *Level 3: LSS Readiness for Change*. A total of 150 KB rules have been triggered in this module and out of these, the system has categorised 101 as GPs and 49 have been categorised as BPs. The 49 bad points are classified into different problem categories (6 PC-1, 2 PC-2, 2 PC-3, 10 PC-4, and 29 PC-5) where they represent the activities that need to be improved to achieve the Lean6-SBM benchmark.

In the *ICT* sub-module, the KB Lean6-SBM has identified 44 GPs out of 52 KB rules triggered. On the other hand, 8 KB rules were not met (BPs), indicating a gap in pre-requisites for achieving benchmark. A further analysis of these BPs revealed that the serious problems were in the dimension of *Availability of ICT Masterplan* (3 BPs of which 1 PC-1 and 2 PC-2). The system has identified an improvement opportunity in BEC to redevelop their ICT masterplan as this aspect plays a major role in the transformation stage. Filling this gap could help the organisation to control different ICT tools acquired by the departments. Furthermore, it will facilitate the roadmap towards improving the current weak integration of information with customers and suppliers.

In the *Share Values* sub-module, a total of 40 KB rules were triggered of which 25 were GPs. In contrast, 15 KB rules were not met (BPs), indicating a gap in pre-requisites for achieving benchmark. A further analysis of these BPs shows that there is no real problem despite the fact that a large number of bad points has been identified by the system. All these BPs are categorised under category PC-5 of which the majority of them are under the dimension of *LSS Project Manager*. The KB rules have shown a higher rate of leadership competencies' percentage levels (e.g. 45% in *functional know-how*) than the recommended ones (25–30%). This will lead to de-grading in other competencies like the *ability to manage change* which is crucial during the transformation into an LSS organisation. Therefore, ignoring this gap may reveal an increase in the severity of other interrelated aspects in future.

Table 7. 11 GAP analysis results of the Organisation BEC Level 3 - LSS Readiness for Change

Level 3: *LSS Readiness for Change* GAP Analysis: BEC

Sub-module	Dimensions	No. KB rules	Good Point	Bad Point	Problem Category				
					1	2	3	4	5
ICT	Availability of ICT Masterplan	19	14	5	1	2	2	0	0
	Legacy Systems	33	30	3	0	0	0	3	0
	Sub-total	**52**	**44**	**8**	**1**	**2**	**2**	**3**	**0**
Share Values	LSS Project Manager	12	3	9	0	0	0	0	9
	Cross-functional Collaboration	5	5	0	0	0	0	0	0
	Shared Believes	23	17	6	0	0	0	0	6
	Sub-total	**40**	**25**	**15**	**0**	**0**	**0**	**0**	**15**
Soft TQM	Commitment	24	15	9	0	0	0	0	9
	Communication	20	6	14	5	0	0	7	2
	Culture	14	11	3	0	0	0	0	3
	Sub-total	**58**	**32**	**26**	**5**	**0**	**0**	**7**	**14**
Total		**150**	**101**	**49**	**6**	**2**	**2**	**10**	**29**

In the sub-module of *Soft TQM*, a total of 58 KB rules were triggered of which 32 were GPs. However, 26 KB rules were not met (BPs), indicating a gap in pre-requisites for achieving benchmark. A further analysis of these BPs shows that a major problem has been identified by the system in the dimension of *Communication* (14 BPs of which 5 PC-1). The significant importance behind measuring effectiveness of the organisation's internal communication (between employees) and external communication (with customers and suppliers) comes from its direct impact on productivity. In a company, which intends to implement LSS, there must be a culture change towards building effective teamwork. Thus, a high level of communication integrity is required throughout all managerial levels.

The above GAP analysis has been used by the KB Lean6-SBM model to produce the AHP analysis. This step is very important as it determines which aspects should be prioritised for further improvements. The integrated AHP will start the analysis by determining the values of priority vectors (PV) in each sub-module. For the sub-modules *ICT*, *Share Values*, and *Soft TQM*, the PV values of each dimension have been calculated as represented in Tables 7.12, 7.13, and 7.14 respectively.

Table 7. 12 ICT AHP analysis with PV for Organisation BEC

ICT	Availability of ICT Masterplan	Legacy Systems	P.V
Availability of ICT Masterplan	1	3	**0.75**
Legacy Systems	1/3	1	0.25

Table 7.12 shows the PV values in the *ICT* sub-module. The values are **0.75** for *Availability of ICT Masterplan*, and 0.25 for *Legacy Systems*. This means that focusing on this sub-module, BEC's priority is to rectify the dimension of *Availability of ICT Masterplan* before attempting the dimension of *Legacy Systems.* The analysis has indicated a serious problem in the *Integration of Information* and *Integration of Infrastructure*.

Table 7. 13 Share Values AHP analysis with PV for Organisation BEC

Share Values	LSS Project Manager	Cross-functional Collaboration	Shared Believes	P.V
LSS Project Manager	1	3	2	0.54
Cross-functional Collaboration	1/3	1	1/2	0.16
Shared Beliefs	1/2	2	1	0.30

Table 7.13 indicates the PV values for the *Share Values* sub-module. The PV values for *LSS Project Manager*, *Cross-functional Collaboration*, and *Shared Beliefs* are **0.54**, 0.16, and 0.30 respectively. Therefore, the priority for BEC to focus on in this sub-module is by improving the dimension *LSS Project Manager* (the analysis highlighted that *Competencies* is the major issue that needs to be tackled) before attempting the dimensions *Shared Beliefs and Cross-functional Collaboration.*

Table 7. 14 Soft TQM AHP analysis with PV for Organisation BEC

Soft TQM	Commitment	Communication	Culture	P.V
Commitment	1	1/4	2	0.20
Communication	4	1	5	**0.68**
Culture	1/2	1/5	1	0.12

Table 7.14 indicates the PV values for the *Soft TQM* sub-module. The PV values for *Commitment*, *Communication*, and *Culture* are 0.20, **0.68**, and 0.12 respectively. Therefore, the priority for BEC to focus on in this sub-module is to improve the dimension *Communication* (this was highlighted due to the lack of the organisation's awareness in measuring the effectiveness of internal and external communication) before attempting the dimensions *Commitment* and *Culture.*

The next analysis uses the same AHP process to determine the PV values at the sub-modules' stage of *ICT*, *Share Values*, and *Soft TQM*. The summary of these sub-modules PV values is tabulated in Table 7.15. The values are 0.20 for *ICT*, 0.31 for *Share Values*, and **0.49** for *Soft TQM*. This means that by focusing on this module, BEC's priority is to rectify the sub-module of *Soft TQM,* followed by the sub-module *Share Values,* and finally the sub-module *ICT.*

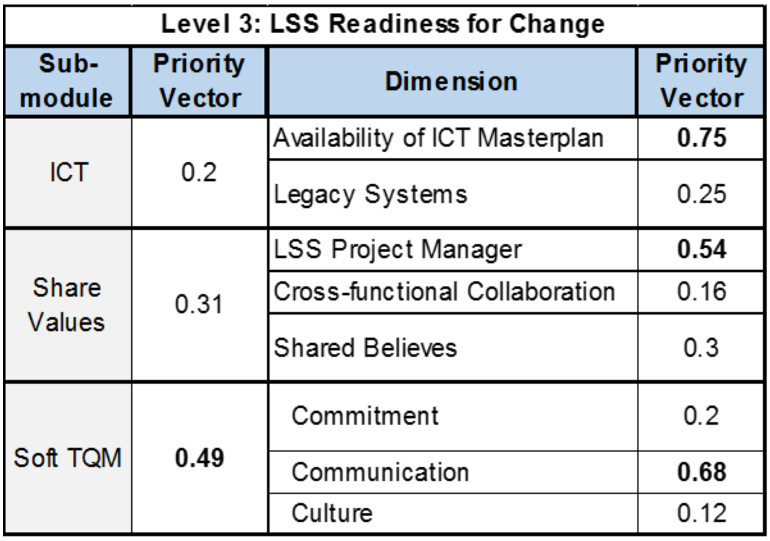
Table 7. 15 Level 3: LSS Readiness for Change AHP analysis with PV for Organisation BEC

Level 3	ICT	Share Values	Soft TQM	P.V
ICT	1	1/2	1/2	0.20
Share Values	2	1	1/2	0.31
Soft TQM	2	2	1	**0.49**

Table 7.16 summarises the AHP-PV values for each of the dimensions and sub-modules for the *LSS Readiness for Change* module. The KB Lean6-SBM analysis proposes that BEC should firstly centre their efforts in resolving the area of *Soft TQM* due to the highest PV of 0.49. The KB Lean6-SBM also requires BEC to improve the *Communication* dimension which has a PV of 0.68.

The KB Lean6-SBM analysis recommends that BEC should then focus on the *Share Values* sub-module (PV = 0.31) before proceeding to improve *ICT*. In the *Share Values* sub-module, more attention has to be given to the *LSS Project Manager* dimension that has a PV of 0.54, whereas in the *ICT* sub-module, BEC needs to concentrate on the *Availability of ICT Masterplan* dimension (PV = 0.75).

Table 7. 16 Summary of AHP PV values for Level 3: LSS Readiness for Change for Organisation BEC



Level 3: LSS Readiness for Change			
Sub-module	**Priority Vector**	**Dimension**	**Priority Vector**
ICT	0.2	Availability of ICT Masterplan	**0.75**
		Legacy Systems	0.25
Share Values	0.31	LSS Project Manager	**0.54**
		Cross-functional Collaboration	0.16
		Shared Believes	0.3
Soft TQM	**0.49**	Commitment	0.2
		Communication	**0.68**
		Culture	0.12

In summary, for Level 3, the KB Lean6-SBM model analysis has recorded the GAP analysis of 49 BPs from 150 KB rules triggered. This revealed that BEC is 32.67% below the benchmark standard in their readiness for change capability to implement LSS. The KB Lean6-SBM analysis concluded that BEC needs to take action to improve the *Communication* dimension in the *Soft TQM* sub-module.

7.3.5 Organisation BEC: Level 4 – LSS Sustainable Building Maintenance Perspective

The *Level 4: LSS Sustainable Building Maintenance Perspective* of the Lean6-SBM model consists of three sub-modules: *Legal*, *Technical*, and *Administrative* as shown in Figure 7.5. In this Level, the KB System measures the strength of the organisation's building maintenance taxonomy in dealing with the transformation into an LSS environment.

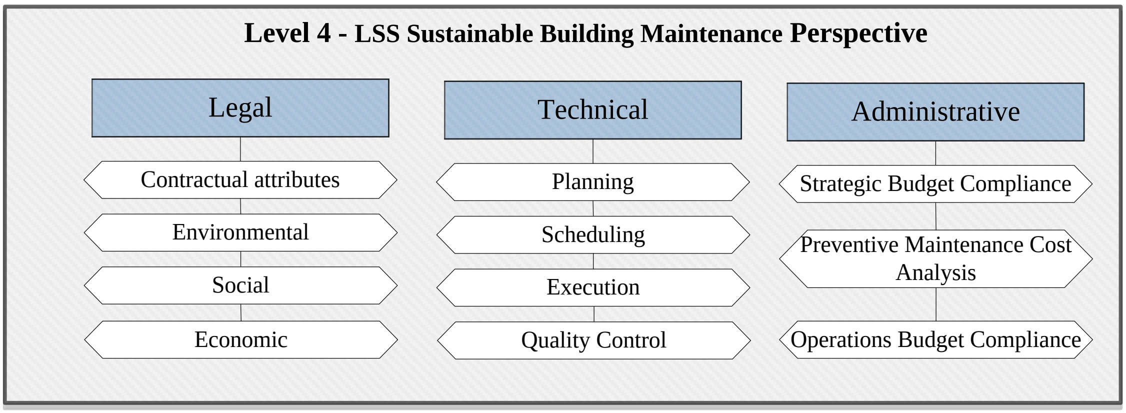


Figure 7. 5 Organisation BEC: Level 4 - LSS Sustainable Building Maintenance Perspective

In this section, *Level 4: LSS Sustainable Building Maintenance Perspective* helps to capture data about BEC's contractual and sustainability attributes, work order life cycle, and about the organisation's PM administrative commitment. The rules embedded in the module will establish relationships, converting that data into information. By assessing and comparing the level of performance of BEC with the system benchmark, the module will convert that information into recommendations about operational issues of the organisation (knowledge or know-how).

As described in Chapter 6, the *Legal* sub-module will be assessed based on four dimensions: *Contractual Attributes, Environmental*, *Social*, and *Economic* whereas the *Technical* sub-module will cover the area of PM *Work Orders (Planning, Scheduling, Execution, and Quality Control)*. On the other hand, the *Administrative* sub-module contains the dimensions of *Strategic Budget Compliance, Preventive Maintenance Cost Analysis, and Operations Budget Compliance*.

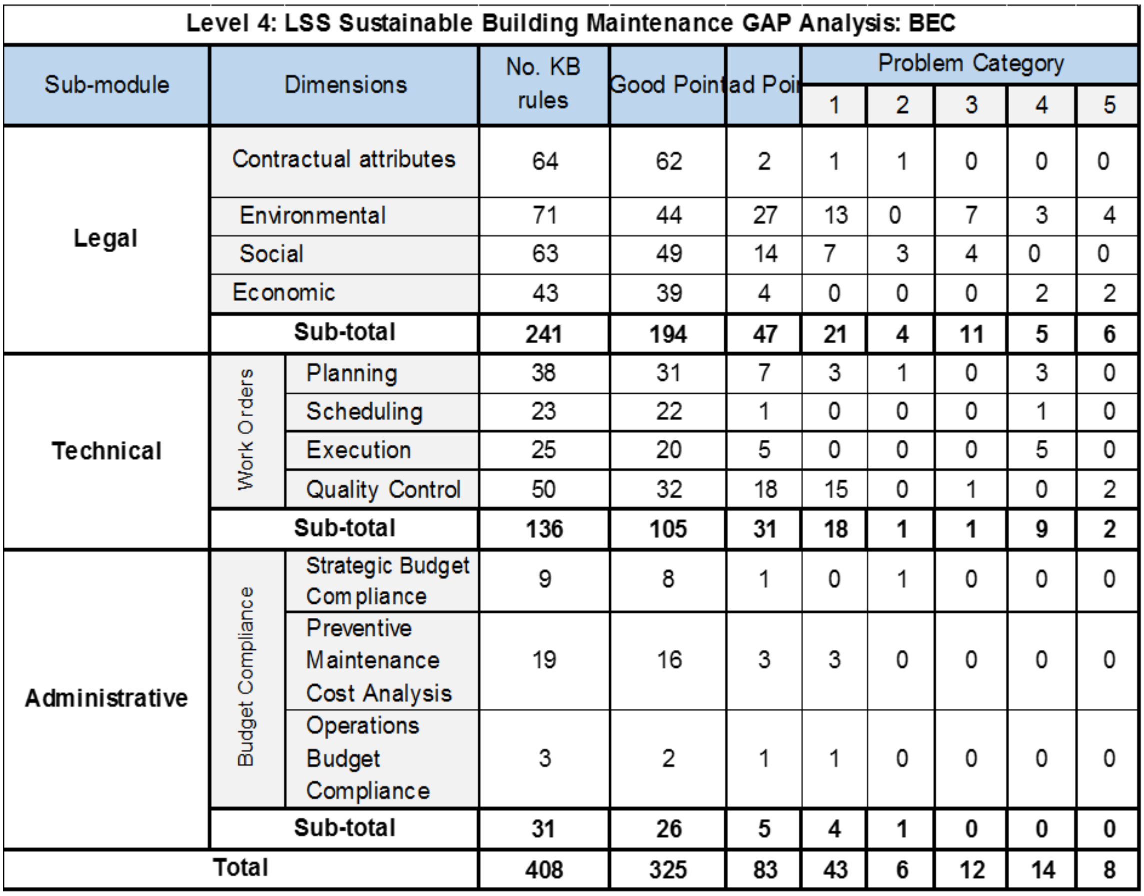
Table 7.17 summarised the BEC GAP analysis results of the *Level 4: LSS Sustainable Building Maintenance Perspective*. A total of 408 KB rules have been triggered in this module and, out of these, the system has categorised 325 as GPs and 83 have been categorised as BPs. The 83 bad points are classified into different problem categories (43 PC-1, 6 PC-2, 12 PC-3, 14 PC-4, and 8 PC-5) where they represent the activities that need to be improved to achieve the Lean6-SBM benchmark.

In the *Legal* sub-module, the KB Lean6-SBM has identified 194 GPs out of 241 KB rules triggered. However, there were 47 KB rules that were not achieved (BPs), indicating a gap in pre-requisites for achieving benchmark. The analysis shows that BEC is practising towards the Lean6-SBM benchmark standard in the aspects of *Scope of Work, Specification,* and *Conditions of Contract*. Nevertheless, a deeper analysis of the BPs signifies that the major problematic area is in the dimensions of *Environmental* (27 BPs of which 13 PC-1) followed by *Social* (14 BPs of which 7 PC-1 and 3 PC-2).

With regards to *Environmental,* the KB rules have deduced no monitoring and targeting schemes employed for energy use and water consumption at BEC, which leads to no attention paid to adopting water/energy-saving measures and leak detection techniques at base offices, workshops, and site locations. This will consequently affect the organisation’s contribution towards sustainability as well as its long-term financial performance. Another critical aspect in the *Environmental* dimension is that BEC has to invest in implementing 5S Lean in waste management prior to implementing the DMAIC cycle. This will contribute a huge saving as the number of BEC site locations has increased dramatically.

In the dimension of *Social*, ensuring health and comfort in the work environment has become an essential part which is legally enforced. The KB rules have identified a gap in measuring the carbon footprint at BEC. In addition, a lack of effort has been recorded towards reducing noise in the workplace. Missing these two aspects will cause a lack of control of being a sustainable organisation. Also, these motivate the long-term health effects on employees (e.g. indoor air quality, hearing capacity), and equipment (e.g. overheating, vibration defects).

Table 7. 17 GAP analysis results of the Organisation BEC Level4 - LSS Sustainable Building Maintenance Perspective



Level 4: LSS Sustainable Building Maintenance GAP Analysis: BEC

Sub-module	Dimensions		No. KB rules	Good Poin	ad Poi	Problem Category				
						1	2	3	4	5
Legal	Contractual attributes		64	62	2	1	1	0	0	0
	Environmental		71	44	27	13	0	7	3	4
	Social		63	49	14	7	3	4	0	0
	Economic		43	39	4	0	0	0	2	2
	Sub-total		**241**	**194**	**47**	**21**	**4**	**11**	**5**	**6**
Technical	Work Orders	Planning	38	31	7	3	1	0	3	0
		Scheduling	23	22	1	0	0	0	1	0
		Execution	25	20	5	0	0	0	5	0
		Quality Control	50	32	18	15	0	1	0	2
	Sub-total		**136**	**105**	**31**	**18**	**1**	**1**	**9**	**2**
Administrative	Budget Compliance	Strategic Budget Compliance	9	8	1	0	1	0	0	0
		Preventive Maintenance Cost Analysis	19	16	3	3	0	0	0	0
		Operations Budget Compliance	3	2	1	1	0	0	0	0
	Sub-total		**31**	**26**	**5**	**4**	**1**	**0**	**0**	**0**
Total			**408**	**325**	**83**	**43**	**6**	**12**	**14**	**8**

In the *Technical* sub-module, a total of 136 KB rules were triggered of which 105 were GPs. However, 31 KB rules were not met (BPs), indicating a gap in pre-requisites for achieving benchmark. A further analysis of these BPs shows that a pivotal problem has been identified by the system in the dimension of *Quality Control* (18 BPs of which 15 PC-1). This dimension is extremely important as a pre-requisite before implementing LSS. Having an independent quality control department in parallel with the PM department has become a major issue that needs to be resolved at BEC. Besides having close monitoring and control of the work standards, the quality department can raise the level of reporting PM performance and work with other departments to enhance further business process improvements.

The last sub-module in Level 4 is *Administrative*. A total of 31 KB rules were triggered of which 26 were GPs. However, 5 KB rules were not met (BPs), indicating a gap in pre-requisites for achieving benchmark. A further analysis of these BPs shows that a key problem is identified in the dimension of *Operations Budget Compliance* (1 BP of which 1 PC-1) simply by not achieving the BS EN 15341:2007 standard (target = 15%–18%). The next close critical dimension is the *Preventive Maintenance Cost Analysis* (3 BPs of which 3 PC-1). Having effective maintenance cost analysis is crucial in measuring cost of poor quality (COPQ) which formulates the problem statement in selecting DMAIC projects. BEC needs to improve this by considering the cost of the seven major wastes of quality as part of the total PM cost.

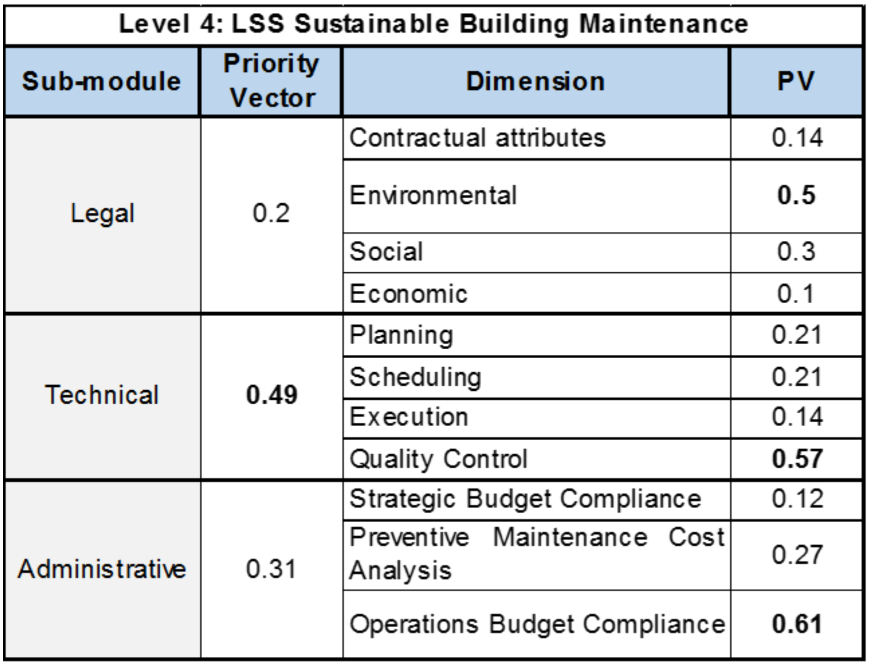
Again, the above GAP analysis has been used by the KB Lean6-SBM model to produce the AHP analysis. This step is substantial as it determines which aspects should come be prioritised for further improvements. The integrated AHP will start the analysis by determining the values of priority vectors (PV) in each sub-module. Calculation for AHP-PV has been done for each Level, sub-module and its dimensions, however, for the sake of brevity, they are shown in the summary table (Table 7.18).

Table 7.18 summarises the AHP-PV values for each of the dimensions and sub-modules for the *LSS Sustainable Building Maintenance Perspective* module. The KB Lean6-SBM analysis proposes that BEC should firstly centre their efforts in resolving the area of *Technical* due to the highest PV of 0.49. The KB Lean6-SBM also requires BEC to improve the *Quality Control* dimension which has a PV of 0.57.

The KB Lean6-SBM analysis recommends that BEC should then focus on the *Administrative* sub-module (PV = 0.31) before proceeding to improve *Legal*. In the Administrative sub-module, more attention has to be given to the *Operations*

Budget Compliance dimension that has a PV of 0.61, whereas in the *Legal* sub-module, BEC needs to concentrate on the *Environmental* dimension (PV = 0.50).

Table 7. 18 Summary of AHP-PV values for Level 4 - LSS Sustainable Building Maintenance Perspective for Organisation BEC



Level 4: LSS Sustainable Building Maintenance			
Sub-module	**Priority Vector**	**Dimension**	**PV**
Legal	0.2	Contractual attributes	0.14
		Environmental	**0.5**
		Social	0.3
		Economic	0.1
Technical	**0.49**	Planning	0.21
		Scheduling	0.21
		Execution	0.14
		Quality Control	**0.57**
Administrative	0.31	Strategic Budget Compliance	0.12
		Preventive Maintenance Cost Analysis	0.27
		Operations Budget Compliance	**0.61**

In summary, for Level 4, the KB Lean6-SBM model analysis has recorded the GAP analysis of 83 BPs from 408 KB rules triggered, which suggested that BEC's performance is 20% below the benchmark standard in their building maintenance taxonomy capability to implement LSS. The KB Lean6-SBM analysis concluded that BEC needs to take immediate actions to improve the *Quality Control* dimension in the *Technical* sub-module.

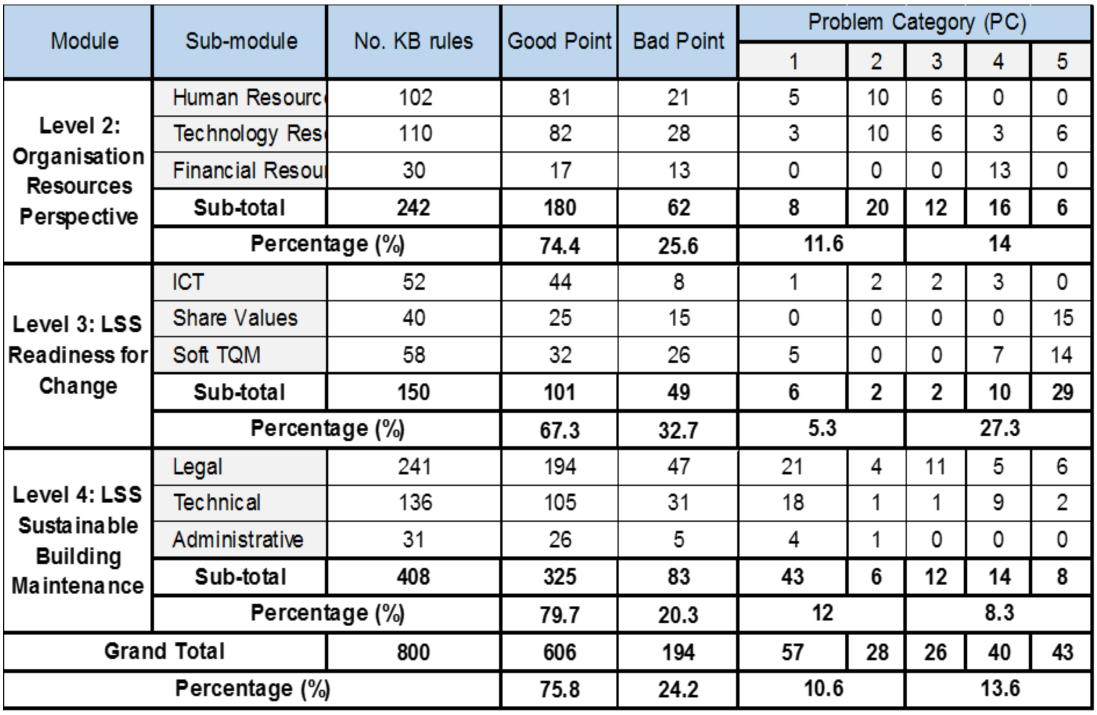
7.4 Organisation BEC: Validation Discussion of KB Lean6-SBM Model

As discussed for each module in Section 7.3, this section will summarise the results analysis at BEC based on the applied validation process.

7.4.1 Summarised KB Lean6-SBM Output for Organisation BEC

Based on the KB Lean6-SBM model analysis, Table 7.19 illustrates the summarised results for BEC. 800 KB rules were triggered in these modules – the output shows 606 GPs representing the readiness of BEC towards Lean6-SBM, however, 194 BPs were identified by the model based on the BEC user feedback, which demonstrates the overall company performance is about 24% lower than the designed benchmark standard. Yet, the KB Lean6-SBM model has considered categories PC-1 and PC-2 as the major problematic areas, whereas category PC-3 and above are minor problems. Obviously, it can be seen from Table 7.19 that BEC has 10.6% of the BPs as major problematic areas and 13.6% of the BPs as minor problems. The detailed breakdown of the modules' (Level 2–Level 4) BP percentages can be highlighted in ratios (serious:unserious) as 25.6% (11.6:14), 32.7% (5.3:27.3), and 20.3% (12:8.3) respectively.

Table 7. 19 Summary of GAP Analysis Results for Organisation BEC



Module	Sub-module	No. KB rules	Good Point	Bad Point	Problem Category (PC)				
					1	2	3	4	5
Level 2: Organisation Resources Perspective	Human Resourc	102	81	21	5	10	6	0	0
	Technology Res	110	82	28	3	10	6	3	6
	Financial Resou	30	17	13	0	0	0	13	0
	Sub-total	**242**	**180**	**62**	**8**	**20**	**12**	**16**	**6**
	Percentage (%)		**74.4**	**25.6**	**11.6**		**14**		
Level 3: LSS Readiness for Change	ICT	52	44	8	1	2	2	3	0
	Share Values	40	25	15	0	0	0	0	15
	Soft TQM	58	32	26	5	0	0	7	14
	Sub-total	**150**	**101**	**49**	**6**	**2**	**2**	**10**	**29**
	Percentage (%)		**67.3**	**32.7**	**5.3**		**27.3**		
Level 4: LSS Sustainable Building Maintenance	Legal	241	194	47	21	4	11	5	6
	Technical	136	105	31	18	1	1	9	2
	Administrative	31	26	5	4	1	0	0	0
	Sub-total	**408**	**325**	**83**	**43**	**6**	**12**	**14**	**8**
	Percentage (%)		**79.7**	**20.3**	**12**		**8.3**		
Grand Total		**800**	**606**	**194**	**57**	**28**	**26**	**40**	**43**
Percentage (%)			**75.8**	**24.2**	**10.6**		**13.6**		

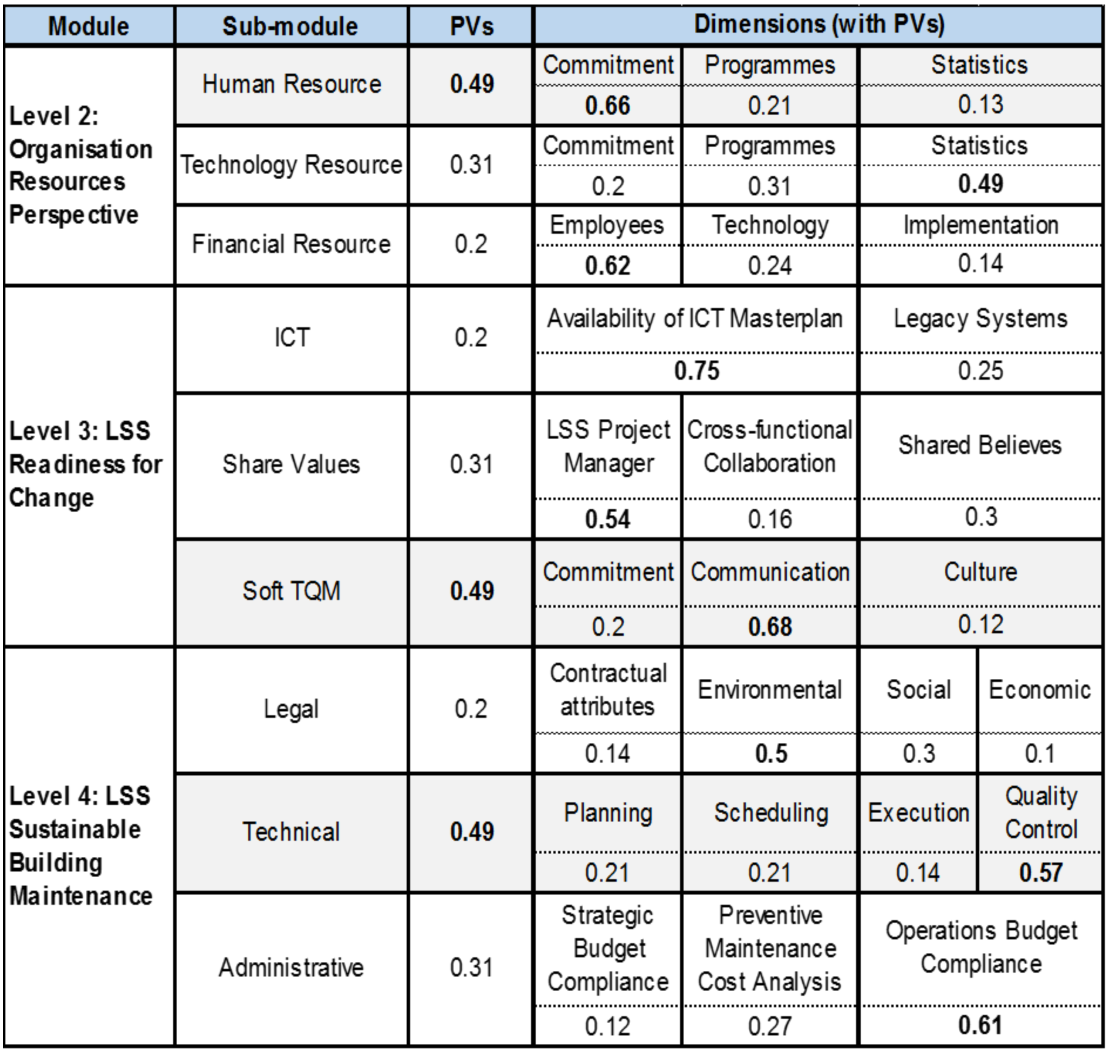
In *Level 2: Organisation Resources Perspective,* the most serious problems were identified in the *Human Resource* sub-module and specifically in the *Commitment* dimension which (from the literature) claims to be one of the most key failure factors in implementing LSS. The second problematic sub-module is the *Technology Resource*, where lack of records has been triggered in the *Employee Participation* aspect with regards to improving technology development. This has caused a gap in measurement with the desired statistical level. The last sub-module in *Level 2* is *Financial Resource*, which shows that financial benefits at

BEC are still below the employees' expectations that will proportionally affect their satisfaction and, hence, the overall productivity performance.

Based on the output results of *Level 3: LSS Readiness for Change*, the most critical part was the *Soft TQM* sub-module. The *Communication* dimension has proved how internal and external factors are incorporated to form a crucial soft element that needs immediate improvement at BEC. The second serious sub-module in *Level 3* is *Share Values*. The analysis shows that BEC used to dedicate project managers in their PM programmes who were under the competencies level specified by the KB Lean6-SBM. The least important sub-module in this Level is the *ICT*. The analysis has shown a gap in facilitating informatics integration with customers and suppliers besides unavailability of a concrete ICT masterplan.

Lastly, for the module of *LSS Sustainable Building Maintenance*, the key sub-module identified by the system was *Technical* in which a remarkable gap was created in the dimension of *Quality Control*. In fact, BEC has not assigned the measurement of the quality performance to an independent department, which as a consequence, caused negligence to over-production, waiting time, and excess motion wastes. Furthermore, there is no minimum/maximum quality standards in executing PM work orders which might cause unjustified increment in rework and defects (waste) backlog.

Table 7. 20 Summary of AHP-PV values for Organisation BEC



Module	Sub-module	PVs	Dimensions (with PVs)			
Level 2: Organisation Resources Perspective	Human Resource	**0.49**	Commitment	Programmes	Statistics	
			0.66	0.21	0.13	
	Technology Resource	0.31	Commitment	Programmes	Statistics	
			0.2	0.31	**0.49**	
	Financial Resource	0.2	Employees	Technology	Implementation	
			0.62	0.24	0.14	
Level 3: LSS Readiness for Change	ICT	0.2	Availability of ICT Masterplan		Legacy Systems	
			0.75		0.25	
	Share Values	0.31	LSS Project Manager	Cross-functional Collaboration	Shared Believes	
			0.54	0.16	0.3	
	Soft TQM	**0.49**	Commitment	Communication	Culture	
			0.2	**0.68**	0.12	
Level 4: LSS Sustainable Building Maintenance	Legal	0.2	Contractual attributes	Environmental	Social	Economic
			0.14	**0.5**	0.3	0.1
	Technical	**0.49**	Planning	Scheduling	Execution	Quality Control
			0.21	0.21	0.14	**0.57**
	Administrative	0.31	Strategic Budget Compliance	Preventive Maintenance Cost Analysis	Operations Budget Compliance	
			0.12	0.27	**0.61**	

The next priority sub-module was *Administrative*, where the company has not met the BS EN 15341:2007 standard in the dimension of *Operations Budget Compliance.* The *Environmental* dimension in the *Legal* sub-module was the third critical part in this Level. The system output highlights that BEC has not utilised any water/energy-saving techniques to optimise their facilities' consumption. Besides, the 5S Lean technique has not yet been implemented in the waste management department.

The KB Lean6-SBM is embedded with AHP, which also supports the organisation (BEC) in prioritising the decision, by facilitating the PV values for each and every part of the model. Table 7.20 illustrates the PV values for each perspective (Level 2–Level 4), which are used to formulate the developed KB Lean6-SBM framework as depicted in Figure 7.6 with the critical areas highlighted.

7.4.1.1 Priority 1 Improvements for Organisation BEC

The developed Lean6-SBM framework shown in Figure 7.6 illustrates a Priority 1 visual improvement roadmap for BEC prioritised by the KB-AHP-GAP System. Starting from the strategic levels, the AHP aspect of the KB System has the highest priority (1) of *Level 2: Organisation Resources Perspective* that BEC should improve. Within this perspective, the sub-module *Human Resource* has been identified as the key where the *Commitment* dimension plays the major role. Furthermore, within this *Commitment*, the GAP aspects of the KB System have identified issues specifically involving middle and lower level management in decision making and where concerned with human resource development.

Thereafter, in *Level 3: LSS Readiness for Change*, the KB System has identified the sub-module *Soft TQM* as Priority 1, specifically within the dimension of *Communication* (by raising the awareness in measuring internal and external communication effectiveness). Finally, for *Level 4: LSS Sustainable Building Maintenance Perspective*, the KB System recommendation is to start improvements with the *Technical* sub-module, in which the *Quality Control* dimension has identified unavailability of quality control departments at PM site projects.

One of the important aspects of this developed KB System is to have a complete audit trail of the KB rules that have identified prioritised actions for improvement by the AHP and GAP methodologies in order to achieve benchmark standards. Hence, Figure 7.6 shows the KB System’s prioritised audit trail (Priority 1) in detail, which can be used to assist with decision making, and to develop an action plan for BEC across the whole organisation's Levels (Level 2–Level 4) to achieve the benchmark. In this case, it is recommended to start with the *Commitment* dimension in Level 2, followed by the *Communication* dimension in Level 3, and completed by the *Quality Control* dimension in Level 4. It can be treated in a step-by-step manner as shown and described above, bearing in mind the immediate actions to be taken for the most serious problems which represent 10.6% of the BPs.

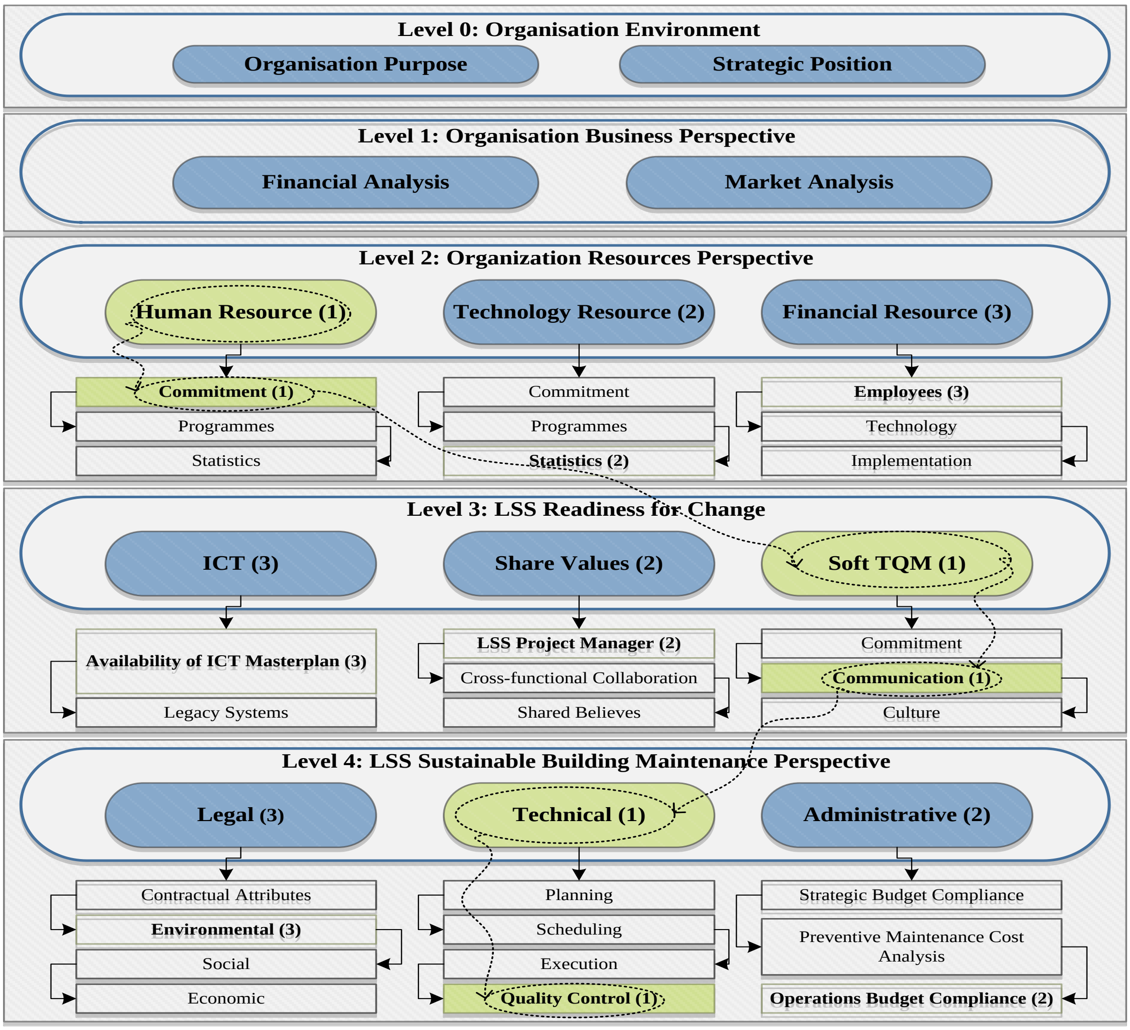
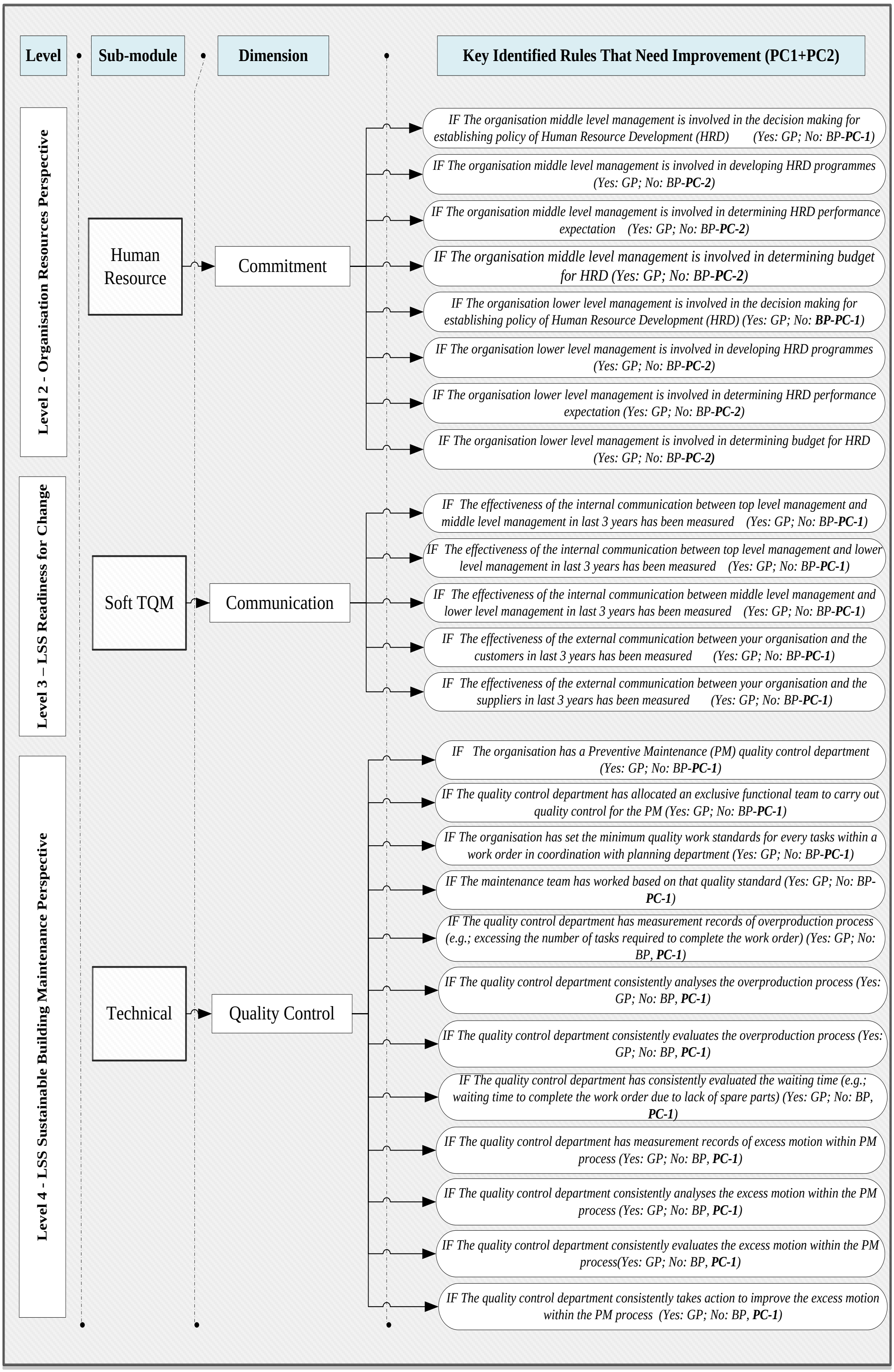


Figure 7. 6 Priority 1 Organisation BEC: Developed Lean6-SBM Framework

In terms of the KB System, AHP Priority 1 and the audit trail of the rules, Figure 7.7 illustrates the key sub-modules, dimensions, and priority rules across all levels for improvements to achieve benchmark standards at BEC. For the sake of brevity, only PC-1 and PC-2 are shown, however, the KB System shows an audit trail for all of the rule-based PCs identified and which need action.



*IF The organisation middle level management is involved in the decision making for establishing policy of Human Resource Development (HRD) (Yes: GP; No: BP-**PC-1**)*

*IF The organisation middle level management is involved in developing HRD programmes (Yes: GP; No: BP-**PC-2**)*

*IF The organisation middle level management is involved in determining HRD performance expectation (Yes: GP; No: BP-**PC-2**)*

*IF The organisation middle level management is involved in determining budget for HRD (Yes: GP; No: BP-**PC-2**)*

*IF The organisation lower level management is involved in the decision making for establishing policy of Human Resource Development (HRD) (Yes: GP; No: **BP-PC-1**)*

*IF The organisation lower level management is involved in developing HRD programmes (Yes: GP; No: BP-**PC-2**)*

*IF The organisation lower level management is involved in determining HRD performance expectation (Yes: GP; No: BP-**PC-2**)*

*IF The organisation lower level management is involved in determining budget for HRD (Yes: GP; No: BP-**PC-2)***

*IF The effectiveness of the internal communication between top level management and middle level management in last 3 years has been measured (Yes: GP; No: BP-**PC-1**)*

*IF The effectiveness of the internal communication between top level management and lower level management in last 3 years has been measured (Yes: GP; No: BP-**PC-1**)*

*IF The effectiveness of the internal communication between middle level management and lower level management in last 3 years has been measured (Yes: GP; No: BP-**PC-1**)*

*IF The effectiveness of the external communication between your organisation and the customers in last 3 years has been measured (Yes: GP; No: BP-**PC-1**)*

*IF The effectiveness of the external communication between your organisation and the suppliers in last 3 years has been measured (Yes: GP; No: BP-**PC-1**)*

*IF The organisation has a Preventive Maintenance (PM) quality control department (Yes: GP; No: BP-**PC-1**)*

*IF The quality control department has allocated an exclusive functional team to carry out quality control for the PM (Yes: GP; No: BP-**PC-1**)*

*IF The organisation has set the minimum quality work standards for every tasks within a work order in coordination with planning department (Yes: GP; No: BP-**PC-1**)*

*IF The maintenance team has worked based on that quality standard (Yes: GP; No: BP-**PC-1**)*

*IF The quality control department has measurement records of overproduction process (e.g.; excessing the number of tasks required to complete the work order) (Yes: GP; No: BP, **PC-1**)*

*IF The quality control department consistently analyses the overproduction process (Yes: GP; No: BP, **PC-1**)*

*IF The quality control department consistently evaluates the overproduction process (Yes: GP; No: BP, **PC-1**)*

*IF The quality control department has consistently evaluated the waiting time (e.g.; waiting time to complete the work order due to lack of spare parts) (Yes: GP; No: BP, **PC-1**)*

*IF The quality control department has measurement records of excess motion within PM process (Yes: GP; No: BP, **PC-1**)*

*IF The quality control department consistently analyses the excess motion within the PM process (Yes: GP; No: BP, **PC-1**)*

*IF The quality control department consistently evaluates the excess motion within the PM process(Yes: GP; No: BP, **PC-1**)*

*IF The quality control department consistently takes action to improve the excess motion within the PM process (Yes: GP; No: BP, **PC-1**)*

Figure 7. 7 Priority 1 Improvements Actions Identified by KB Lean6-SBM System for Organisation BEC

The above figure of the identified key rules shows that BEC has to involve middle and lower level management in HRD programmes and the related decision-making process. Besides not measuring the communication effectiveness in the last three years, this may give an indication that the organisation’s culture is below the standard to sustain the competitive advantage of implementing LSS. Moreover, BEC should focus on establishing quality control departments distributed geographically based on PM projects’ sites.

7.4.1.2 Priority 2 Improvements for Organisation BEC

Figure 7.8 illustrates the developed Lean6-SBM framework for Priority 2. It shows a visual improvement roadmap for BEC prioritised by the KB-AHP-GAP System. Within Level 2*,* the KB System identified the *Technology Resource* sub-module as a second priority in which the *Statistics* dimension is found to be the major problem (driven by the reduction of the employees’ participation in technology improvement within the last three years).

The second priority in Level 3 is the *Share Values* sub-module in which the *LSS Project Manager* dimension has been identified as the most serious problem where a proper selection (of a project manager) must take into consideration certain levels of leadership competencies’ requirements to achieve the benchmark standard.

Lastly, the second priority in Level 4 is the *Administrative* sub-module, which indicates a critical problematic area in the *Operation Budget Compliance* dimension, due to not achieving the British Standard of budget compliance in total preventive maintenance cost with respect to total maintenance cost (target = 15%–18%).

Similarly for Priority 2, Figure 7.8 shows in detail the KB System prioritised audit trail which can be used to assist the decision making, and to develop an action plan for BEC across the analysed organisation Levels. In this case, it is recommended to start with the *Statistics* dimension in Level 2, followed by the *LSS Project Manager* dimension in Level 3, and completed by the *Operations Budget Compliance* dimension in Level 4.

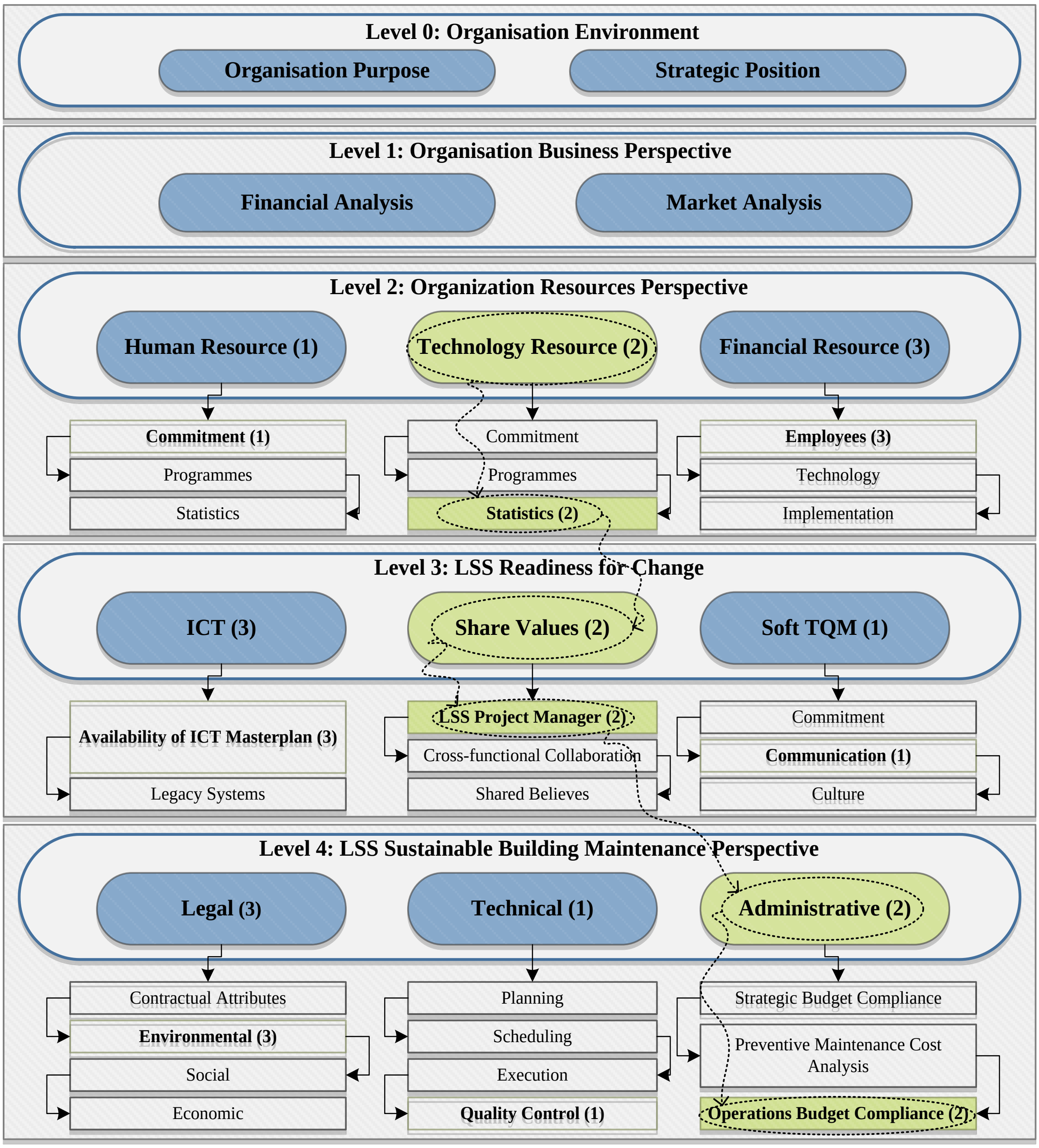


Figure 7. 8 Priority 2 Organisation BEC: Developed Lean6-SBM Framework

In terms of the KB System, AHP Priority 2 and the audit trail of the rules, Figure 7.9 illustrates the key sub-modules, dimensions, and priority rules across all Levels for improvements to achieve benchmark standards at BEC. Again, for the sake of brevity, only PC-1 and PC-2 are shown, however, the KB System shows an audit trail for all of the rule-based PCs identified and which need action.

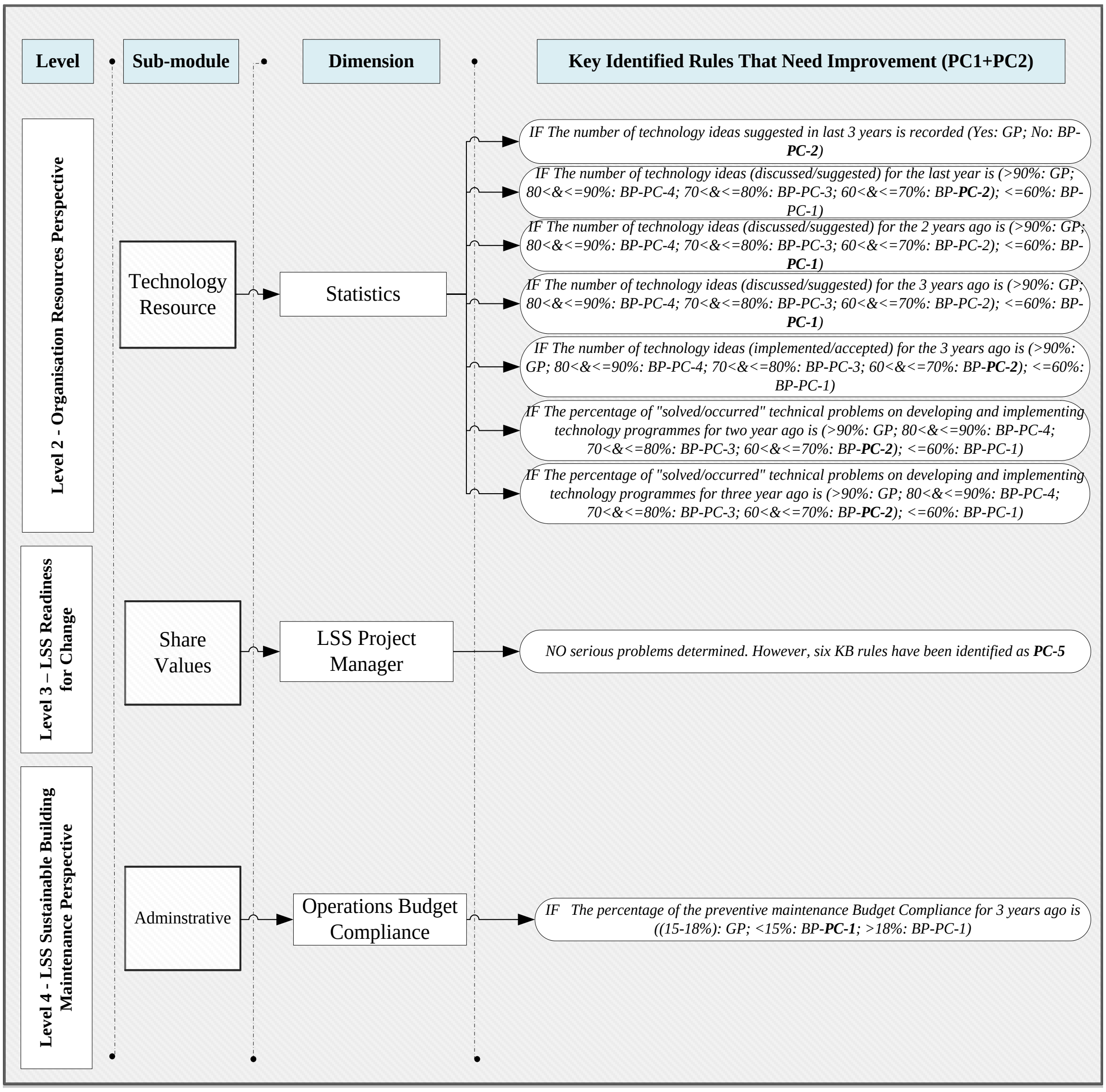


Figure 7. 9 Priority 2 Improvements Actions Identified by KB Lean6-SBM System for Organisation BEC

It can be seen in the figure above that the KB System has not identified any critical issue for Priority 2 improvements in the *LSS Project Manager* dimension. However, there were still some KB rules that have been detected (6 PC-5) by the AHP aspect which might not cause any problem in the short term. Nevertheless, neglecting the same may cascade to future leadership implications. Therefore, it is recommended to address those gaps in order to achieve the Lean6-SBM benchmark standard.

7.4.1.3 Priority 3 Improvements for Organisation BEC

The developed Lean6-SBM framework shown in Figure 7.10 illustrates a Priority 3 visual improvement roadmap for BEC prioritised by the KB-AHP-GAP System. In Level 2, the *Financial Resource* sub-module was identified as Priority 3 in terms of improvement where the *Employees* dimension is the most critical (due to lack of budget allocated to salaries and other benefits).

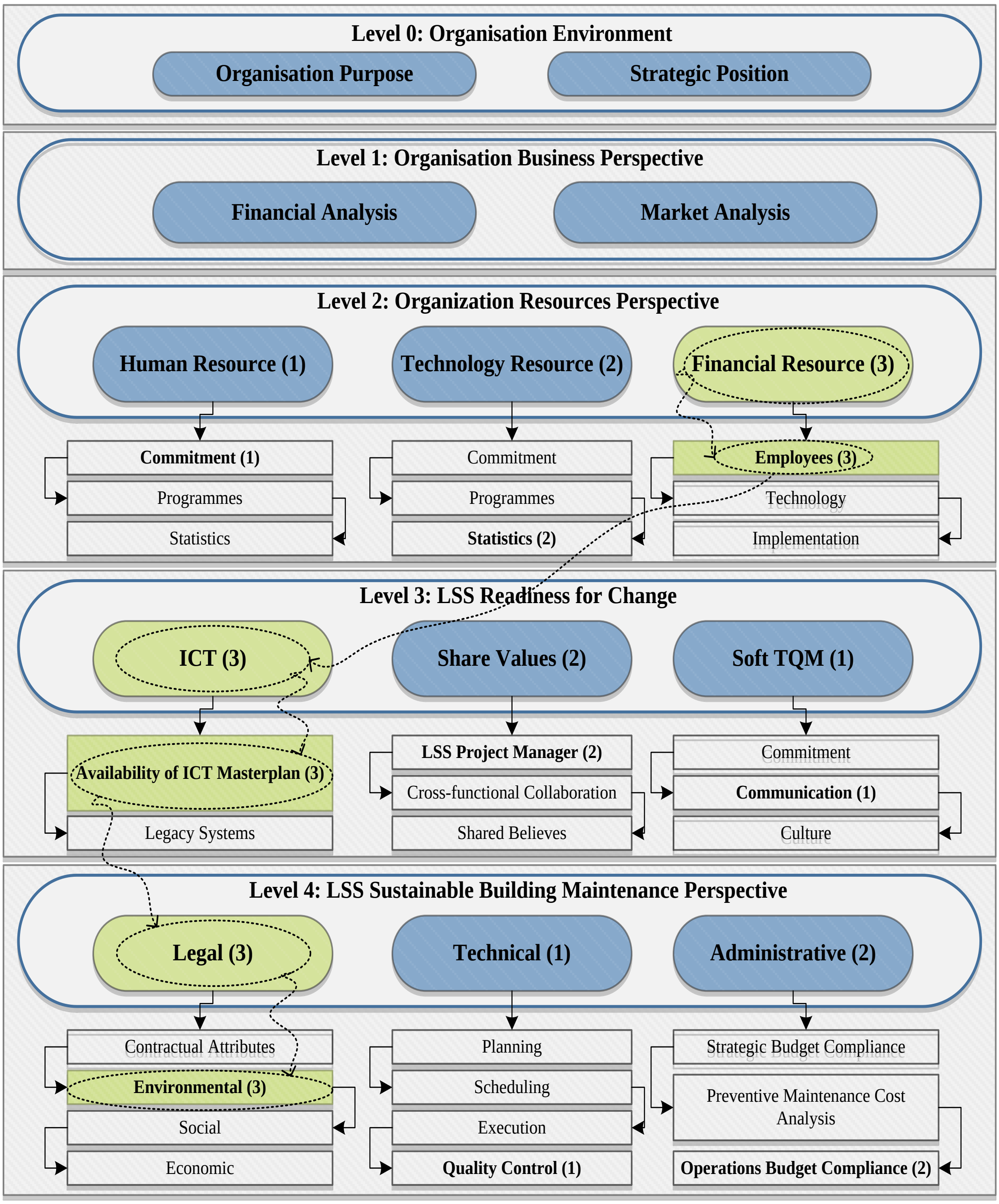


Figure 7. 10 Priority 3 Organisation BEC: Developed Lean6-SBM Framework

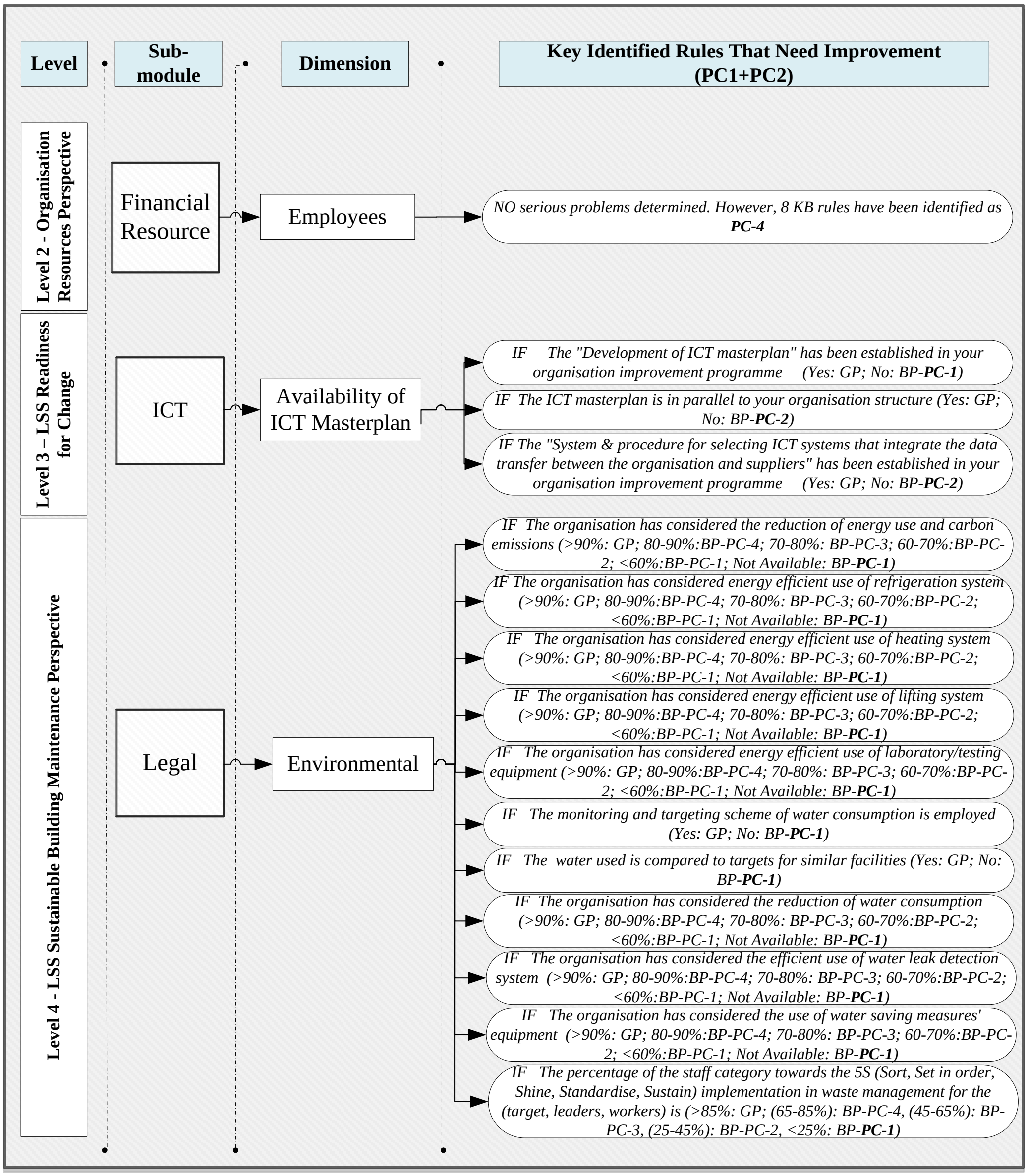
The third priority in Level 3 is the *ICT* sub-module, which is dominated by the dimension of *Availability of ICT Masterplan*, indicating a serious gap in sustaining the informative integration between the organisation's departments as well as between the organisation and suppliers.

Lastly, for Level 4, the KB System has determined a Priority 3 in the *Legal* sub-module, in which the *Environmental* dimension dominates the other sustainability aspects by having a serious gap in reservation of natural resources and control of waste management.

Thus, for Priority 3, Figure 7.10 demonstrates in detail the KB System prioritised audit trail, which can be used to assist in decision making, and to develop an action plan for BEC across the analysed organisation Levels (Level 2–Level 4). In this case, it is recommended to start with the *Employees* dimension in Level 2, followed by the *Availability of ICT Masterplan* dimension in Level 3, and completed by the *Environmental* dimension in Level 4.

With regards to KB System, AHP Priority 3 and the audit trail of the rules, Figure 7.11 illustrates the key sub-modules, dimensions, and priority rules across all Levels for improvements to achieve benchmark standards at BEC.

Again, for the sake of brevity, only PC-1 and PC-2 are shown. Nevertheless, the KB System shows an audit trail for all of the rule-based PCs identified and which need action. It is remarkable to note from the figure mentioned above the large number of serious problems in Level 4, specifically in the dimension of *Environmental* in which the BPs represent more than 38% of the KB rules triggered. In consequence, it is essential for BEC to start filling in these gaps in order to achieve the Lean6-SBM standard of sustainability in the work environment. This has to be actioned simultaneously with other priority aspects in Level 2 and Level 3.



NO serious problems determined. However, 8 KB rules have been identified as ***PC-4***

*IF The "Development of ICT masterplan" has been established in your organisation improvement programme (Yes: GP; No: BP-**PC-1**)*

*IF The ICT masterplan is in parallel to your organisation structure (Yes: GP; No: BP-**PC-2**)*

*IF The "System & procedure for selecting ICT systems that integrate the data transfer between the organisation and suppliers" has been established in your organisation improvement programme (Yes: GP; No: BP-**PC-2**)*

*IF The organisation has considered the reduction of energy use and carbon emissions (>90%: GP; 80-90%:BP-PC-4; 70-80%: BP-PC-3; 60-70%:BP-PC-2; <60%:BP-PC-1; Not Available: BP-**PC-1**)*

*IF The organisation has considered energy efficient use of refrigeration system (>90%: GP; 80-90%:BP-PC-4; 70-80%: BP-PC-3; 60-70%:BP-PC-2; <60%:BP-PC-1; Not Available: BP-**PC-1**)*

*IF The organisation has considered energy efficient use of heating system (>90%: GP; 80-90%:BP-PC-4; 70-80%: BP-PC-3; 60-70%:BP-PC-2; <60%:BP-PC-1; Not Available: BP-**PC-1**)*

*IF The organisation has considered energy efficient use of lifting system (>90%: GP; 80-90%:BP-PC-4; 70-80%: BP-PC-3; 60-70%:BP-PC-2; <60%:BP-PC-1; Not Available: BP-**PC-1**)*

*IF The organisation has considered energy efficient use of laboratory/testing equipment (>90%: GP; 80-90%:BP-PC-4; 70-80%: BP-PC-3; 60-70%:BP-PC-2; <60%:BP-PC-1; Not Available: BP-**PC-1**)*

*IF The monitoring and targeting scheme of water consumption is employed (Yes: GP; No: BP-**PC-1**)*

*IF The water used is compared to targets for similar facilities (Yes: GP; No: BP-**PC-1**)*

*IF The organisation has considered the reduction of water consumption (>90%: GP; 80-90%:BP-PC-4; 70-80%: BP-PC-3; 60-70%:BP-PC-2; <60%:BP-PC-1; Not Available: BP-**PC-1**)*

*IF The organisation has considered the efficient use of water leak detection system (>90%: GP; 80-90%:BP-PC-4; 70-80%: BP-PC-3; 60-70%:BP-PC-2; <60%:BP-PC-1; Not Available: BP-**PC-1**)*

*IF The organisation has considered the use of water saving measures' equipment (>90%: GP; 80-90%:BP-PC-4; 70-80%: BP-PC-3; 60-70%:BP-PC-2; <60%:BP-PC-1; Not Available: BP-**PC-1**)*

*IF The percentage of the staff category towards the 5S (Sort, Set in order, Shine, Standardise, Sustain) implementation in waste management for the (target, leaders, workers) is (>85%: GP; (65-85%): BP-PC-4, (45-65%): BP-PC-3, (25-45%): BP-PC-2, <25%: BP-**PC-1**)*

Figure 7. 11 Priority 3 Improvements Actions Identified by KB Lean6-SBM System for Organisation BEC

7.4.2 Review of the Organisation BEC Validation Process

The validation output of the KB Lean6-SBM model at BEC has shown the system's capability in providing a powerful integration between the KB, GAP, and AHP. The KB System has achieved the main research objectives by identifying the prioritised actions for improvements in each level of the organisation structure. It has also shown the audit trail of the KB rules along with the demonstration of key rules in each Level.

For Priority 1 *Strategic Decision Levels*, it has been identified that BEC should focus on the sub-module *Human Resource* (*Commitment* dimension), and the sub-module *Soft TQM* (*Communication* dimension), whereas for Priority 1 *Operational Decision Levels*, the KB System has recommended concentration on the *Technical* sub-module (*Quality Control* dimension).

In terms of Priority 2 *Strategic Decision Levels*, the KB System has identified that BEC should focus on the sub-module *Technology Resource* (*Statistics* dimension) and the sub-module *Share Values* (*LSS Project Manager* dimension). In the meantime, for Priority 2 *Operational Decision Levels*, the system has suggested improvement of the *Administrative* sub-module (*Operations Budget Compliance* dimension).

Finally, for Priority 3 *Strategic Decision Levels,* the KB System has determined that BEC has to rectify the sub-module *Financial Resource* (*Employees'* dimension) and the sub-module *ICT* (*Availability of ICT Masterplan* dimension), meanwhile for Priority 3 *Operational Decision Levels*, the system has recommended focus on the *Legal* sub-module (*Environmental* dimension).

7.5 Organisation TTC: Validation Discussion of KB Lean6-SBM Model

This section will present the results analysis at TTC organisation based on the applied validation process as discussed earlier in Section 7.3 for organisation BEC. Thus, only the summary results of the validation will be presented for organisation TTC, again for only Levels 0-4.

7.5.1 Summarised KB Lean6-SBM Output for Organisation TTC

Based on the KB Lean6-SBM model analysis for TTC (Appendix B), the total GAP analysis with percentages is tabulated in Table 7.21.

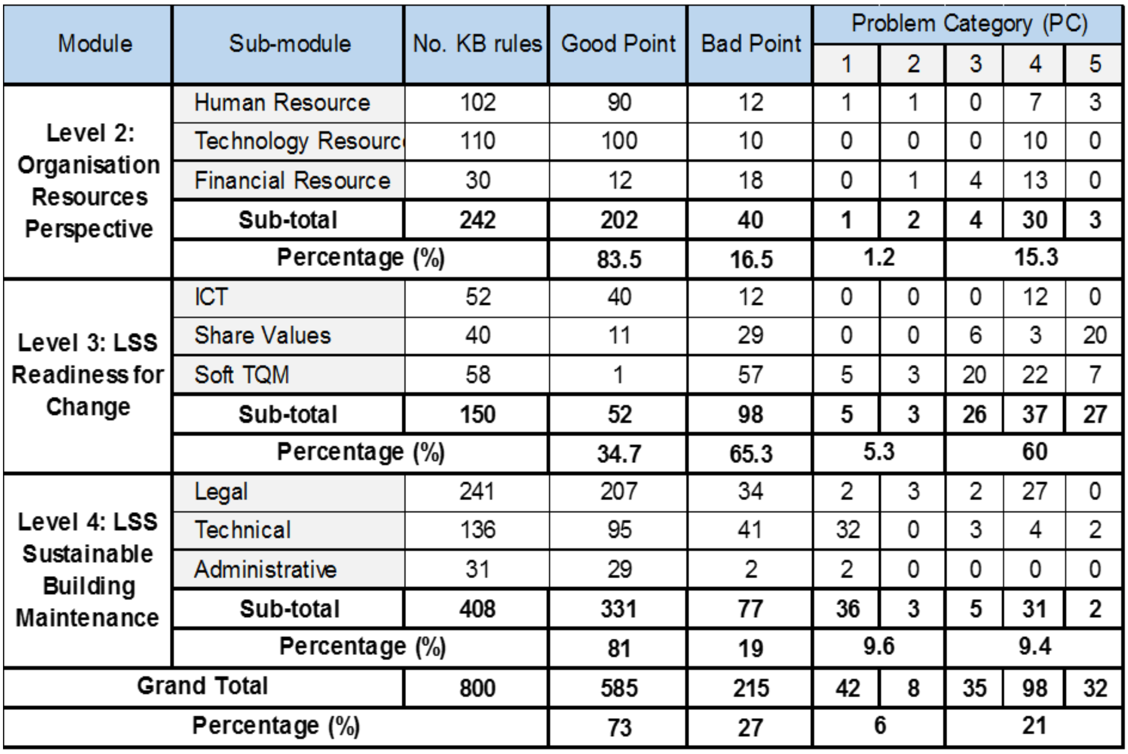
800 KB rules were triggered in these modules. The analysis shows that 215 BPs were identified by the model based on the TTC user response, which demonstrates the overall company performance is about 27% lower than the designed benchmark standard. It can be seen from Table 7.21 that TTC has 6% of the BPs as major problematic areas and 21% of the BPs as minor problems. The detailed breakdown of the modules' (Level 2–Level 4) BPs percentages can be

highlighted in ratios (serious:unserious) as 16.5% (1.2:15.3), 65.3% (5.3:60), and 19% (9.6:9.4) respectively.

In *Level 2: Organisation Resources Perspective,* the most serious problems were identified in the dimension of *Employees* (*Financial Resource* sub-module) due to the struggle in getting better wages and enough training, which accordingly affect their satisfaction, and hence, the overall productivity performance. The second problematic sub-module in TTC is the *Human Resource* where it has been identified that HRD programmes have not been reviewed at all which has consequently created negative effects on other dimensions of the KB Lean6-SBM. The last sub-module in *Level 2* is *Technology Resource*, where lack of records has been triggered in the *Employee Participation* aspect with regards to involvement in improving technology development. This has caused a gap in measurement with the desired statistical level.

Navigating on the output results of *Level 3: LSS Readiness for Change*, the most critical part was the *Communication* dimension (*Soft TQM* sub-module). Again, this soft element has shown a quick and high impact on successful LSS implementation as it incorporates the organisation's culture towards excellence objectives. However, TTC has to centre their efforts by focusing on enhancing the communicating plan between different levels in this dimension. The second serious sub-module in *Level 3* is *Share Values*. The analysis shows that TTC has not achieved the benchmark for the leadership competencies while dedicating project managers for the PM programmes. The least important sub-module in this *Level* is *ICT*. The analysis has identified a gap in *Legacy Systems* due to inefficient service level agreement (SLA) and system architecture in the last two years which helps in distracting the flow of information between departments. This scenario became worse with improper scheduling of data cleansing (removing/replacing/modifying of inaccurate data) compared with the size of the business at TTC that required very regular data scrubbing activities.

Table 7. 21 Summary of GAP Analysis Results for Organisation TTC

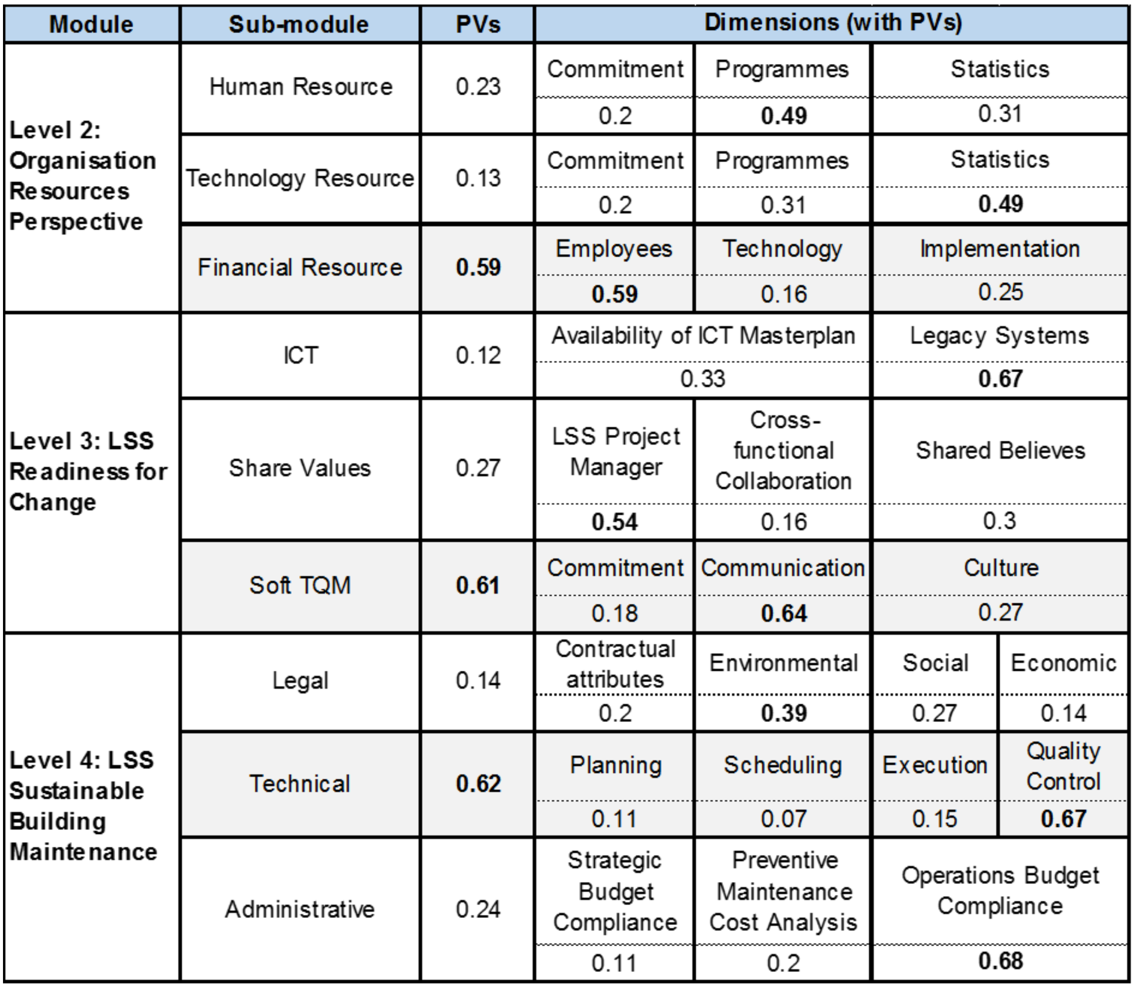


Module	Sub-module	No. KB rules	Good Point	Bad Point	Problem Category (PC)				
					1	2	3	4	5
Level 2: Organisation Resources Perspective	Human Resource	102	90	12	1	1	0	7	3
	Technology Resourc	110	100	10	0	0	0	10	0
	Financial Resource	30	12	18	0	1	4	13	0
	Sub-total	**242**	**202**	**40**	**1**	**2**	**4**	**30**	**3**
	Percentage (%)		**83.5**	**16.5**	**1.2**		**15.3**		
Level 3: LSS Readiness for Change	ICT	52	40	12	0	0	0	12	0
	Share Values	40	11	29	0	0	6	3	20
	Soft TQM	58	1	57	5	3	20	22	7
	Sub-total	**150**	**52**	**98**	**5**	**3**	**26**	**37**	**27**
	Percentage (%)		**34.7**	**65.3**	**5.3**		**60**		
Level 4: LSS Sustainable Building Maintenance	Legal	241	207	34	2	3	2	27	0
	Technical	136	95	41	32	0	3	4	2
	Administrative	31	29	2	2	0	0	0	0
	Sub-total	**408**	**331**	**77**	**36**	**3**	**5**	**31**	**2**
	Percentage (%)		**81**	**19**	**9.6**		**9.4**		
Grand Total		**800**	**585**	**215**	**42**	**8**	**35**	**98**	**32**
Percentage (%)			**73**	**27**	**6**		**21**		

The last module validated by TTC was the *Level 4: LSS Sustainable Building Maintenance*. The first key sub-module identified by the system was *Technical* in which a remarkable gap was created in the dimension of *Quality Control*. In spite of having a site quality control department, the system has identified unavailability of quality measurement records with regards to the seven quality waste practices. Moreover, the records of opening and closing work orders are below the BS EN 15341:2007 trending standard. The next priority sub-module was *Administrative*, where the company has not met the BS EN 15341:2007 standard (15–18%) in the dimension of *Operations Budget Compliance.* The *Environmental* dimension in the *Legal* sub-module was the third critical part in this Level. In this dimension, TTC has not practised any method/technique that contributes to a reduction in water and energy consumption which demonstrates their degree of awareness towards natural resources and hence, sustainability.

Similar to the analysis process carried out for BEC, the KB Lean6-SBM is embedded with AHP to support TTC in prioritising their decisions by facilitating the PV values for each and every part of the model. Table 7.22 illustrates the PV values for each perspective (Level 2–Level 4), which are used to formulate the TTC developed KB Lean6-SBM framework.

Table 7. 22 Summary of AHP-PV values for Organisation TTC



Module	Sub-module	PVs	Dimensions (with PVs)			
Level 2: Organisation Resources Perspective	Human Resource	0.23	Commitment	Programmes	Statistics	
			0.2	**0.49**	0.31	
	Technology Resource	0.13	Commitment	Programmes	Statistics	
			0.2	0.31	**0.49**	
	Financial Resource	**0.59**	Employees	Technology	Implementation	
			0.59	0.16	0.25	
Level 3: LSS Readiness for Change	ICT	0.12	Availability of ICT Masterplan		Legacy Systems	
			0.33		**0.67**	
	Share Values	0.27	LSS Project Manager	Cross-functional Collaboration	Shared Believes	
			0.54	0.16	0.3	
	Soft TQM	**0.61**	Commitment	Communication	Culture	
			0.18	**0.64**	0.27	
Level 4: LSS Sustainable Building Maintenance	Legal	0.14	Contractual attributes	Environmental	Social	Economic
			0.2	**0.39**	0.27	0.14
	Technical	**0.62**	Planning	Scheduling	Execution	Quality Control
			0.11	0.07	0.15	**0.67**
	Administrative	0.24	Strategic Budget Compliance	Preventive Maintenance Cost Analysis	Operations Budget Compliance	
			0.11	0.2	**0.68**	

7.5.1.1 Priority 1 Improvements for Organisation TTC

The developed Lean6-SBM framework shown in Figure 7.12 illustrates a Priority 1 visual improvement roadmap for TTC prioritised by the KB-AHP-GAP System. Starting from the strategic levels, the AHP aspect of the KB System has the highest priority (1) of *Level 2: Organisation Resources Perspective* that TTC should improve. Within this perspective, the sub-module *Financial Resource* has been identified as key where the *Employees* dimension plays the major role. Furthermore, within this *Employees* dimension, the GAP aspects of the KB System have identified issues specifically allocating enough budget for staff training and career development planning in the last year (2015).

Thereafter, in *Level 3: LSS Readiness for Change*, the KB System has identified the sub-module *Soft TQM* as Priority 1 and, specifically within the dimension of *Communication* (by raising the effectiveness of communication with customers). Finally, for *Level 4: LSS Sustainable Building Maintenance Perspective*, the KB System recommendation is to start improvements with the *Technical* sub-module, in which the *Quality Control* dimension has identified unawareness of the seven major wastes of quality.

One of the important aspects of this developed KB System is to have a complete audit trail of the KB rules that have identified prioritised actions for improvement by the AHP and GAP methodologies in order to achieve benchmark standards. Hence, Figure 7.12 shows in detail the KB System prioritised audit trail (Priority 1) which can be used to assist in decision making and to develop an action plan for TTC across all the organisation’s Levels (Level 2–Level 4) to achieve the benchmark. In this case, it is recommended to start with the *Employees* dimension in Level 2, followed by the *Communication* dimension in Level 3, and completed by the *Quality Control* dimension in Level 4. It can be treated in a step-by-step manner as shown and described above, bearing in mind the immediate actions to be taken for the most serious problems which represent 6% of the BPs.

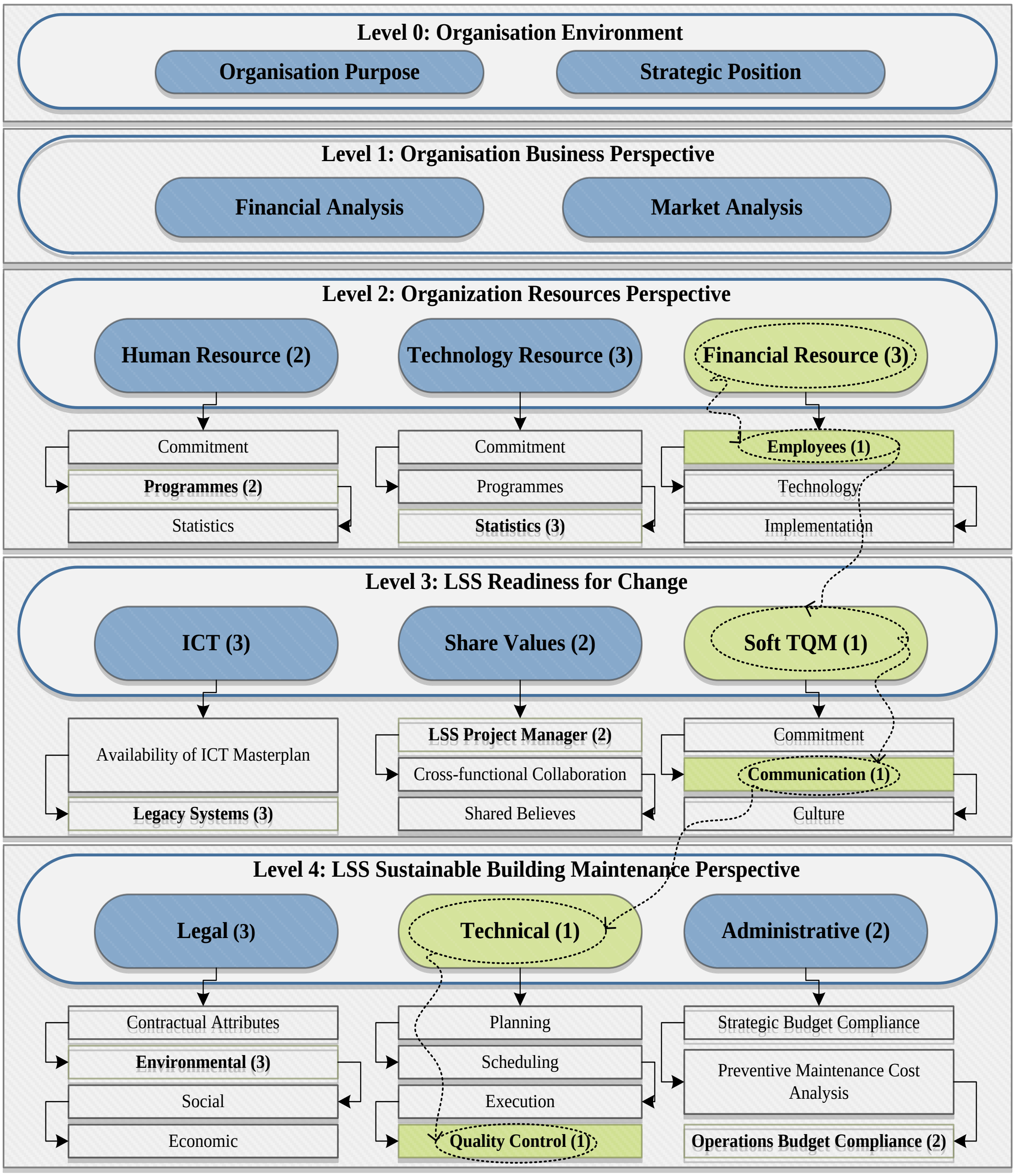
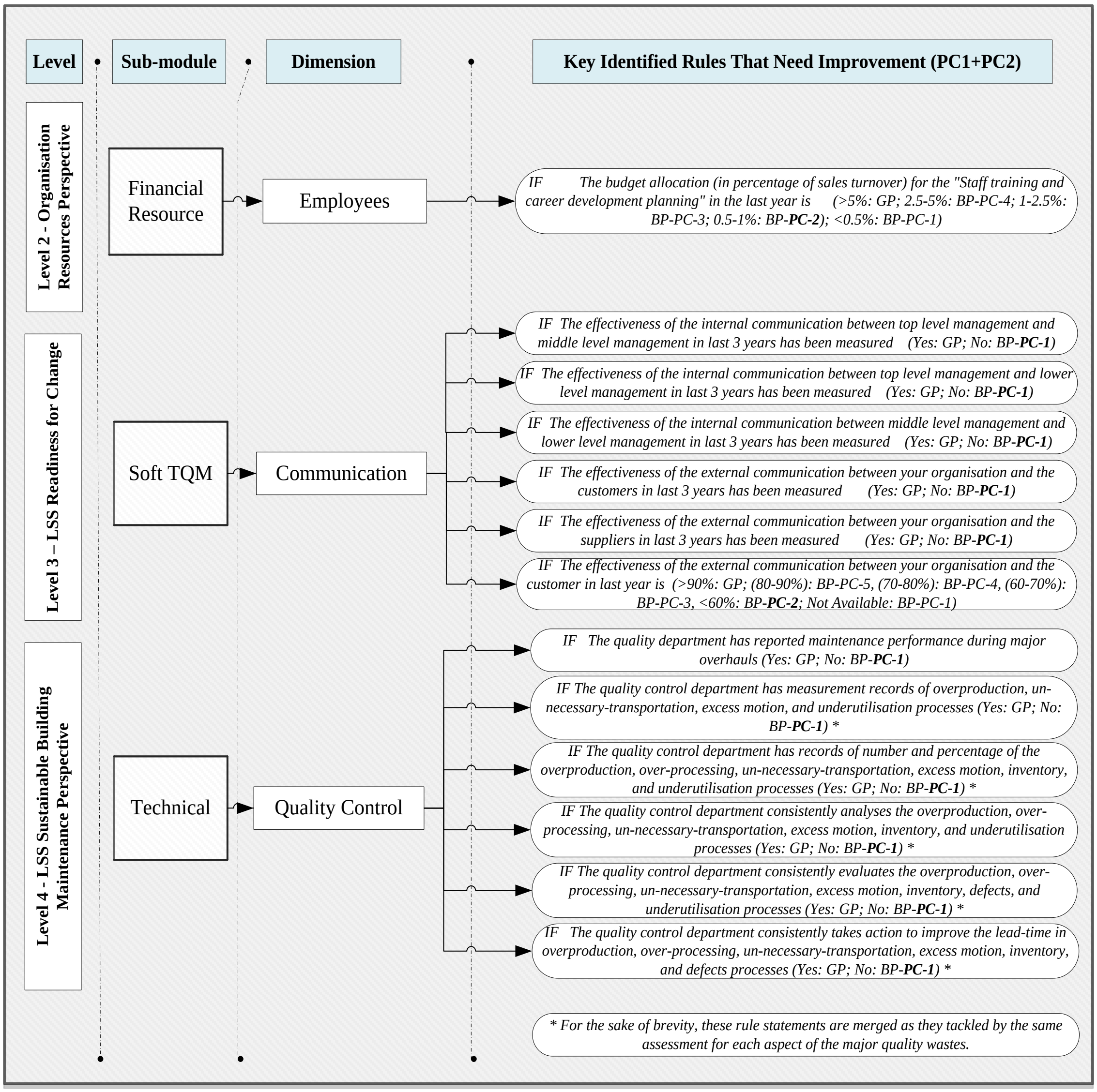


Figure 7. 12 Priority 1 Organisation TTC: Developed Lean6-SBM Framework

In terms of the KB System, AHP Priority 1 and the audit trail of the rules, Figure 7.13 illustrates the key sub-modules, dimensions, and priority rules across all levels for improvements to achieve benchmark standards at TTC. For the sake of brevity, only PC-1 and PC-2 are shown. However, the KB System shows an audit trail for all of the rule-based PCs identified and which need action.



IF The budget allocation (in percentage of sales turnover) for the "Staff training and career development planning" in the last year is (>5%: GP; 2.5-5%: BP-PC-4; 1-2.5%: BP-PC-3; 0.5-1%: BP-**PC-2**); <0.5%: BP-PC-1)

IF The effectiveness of the internal communication between top level management and middle level management in last 3 years has been measured (Yes: GP; No: BP-**PC-1**)

IF The effectiveness of the internal communication between top level management and lower level management in last 3 years has been measured (Yes: GP; No: BP-**PC-1**)

IF The effectiveness of the internal communication between middle level management and lower level management in last 3 years has been measured (Yes: GP; No: BP-**PC-1**)

IF The effectiveness of the external communication between your organisation and the customers in last 3 years has been measured (Yes: GP; No: BP-**PC-1**)

IF The effectiveness of the external communication between your organisation and the suppliers in last 3 years has been measured (Yes: GP; No: BP-**PC-1**)

IF The effectiveness of the external communication between your organisation and the customer in last year is (>90%: GP; (80-90%): BP-PC-5, (70-80%): BP-PC-4, (60-70%): BP-PC-3, <60%: BP-**PC-2**; Not Available: BP-PC-1)

IF The quality department has reported maintenance performance during major overhauls (Yes: GP; No: BP-**PC-1**)

IF The quality control department has measurement records of overproduction, un-necessary-transportation, excess motion, and underutilisation processes (Yes: GP; No: BP-**PC-1**) *

IF The quality control department has records of number and percentage of the overproduction, over-processing, un-necessary-transportation, excess motion, inventory, and underutilisation processes (Yes: GP; No: BP-**PC-1**) *

IF The quality control department consistently analyses the overproduction, over-processing, un-necessary-transportation, excess motion, inventory, and underutilisation processes (Yes: GP; No: BP-**PC-1**) *

IF The quality control department consistently evaluates the overproduction, over-processing, un-necessary-transportation, excess motion, inventory, defects, and underutilisation processes (Yes: GP; No: BP-**PC-1**) *

IF The quality control department consistently takes action to improve the lead-time in overproduction, over-processing, un-necessary-transportation, excess motion, inventory, and defects processes (Yes: GP; No: BP-**PC-1**) *

* For the sake of brevity, these rule statements are merged as they tackled by the same assessment for each aspect of the major quality wastes.

Figure 7. 13 Priority 1 Improvements Actions Identified by KB Lean6-SBM System for Organisation TTC

It is obvious from the above figure that strategically, TTC has to increase the budget allocated to employees' development and training. In addition, the effectiveness of communication between different stakeholders has not been measured for the last three years and this has put the company in a position where they struggle to satisfy existing customers. Operationally, in order for TTC to ease their future LSS projects' implementation, the quality control department has to maintain measurement records of the seven major quality wastes and to start analysing and evaluating them with proper suggestions of an action plan.

7.5.1.2 Priority 2 Improvements for Organisation TTC

Figure 7.14 illustrates the developed Lean6-SBM framework for Priority 2. It shows a visual improvement roadmap for TTC prioritised by the KB-AHP-GAP System. Within Level 2, the KB System identified the *Human Resource* sub-module as a second priority in which the *Programmes* dimension is found to be the major problem (driven by having no review of HRD programmes in addition to unavailability of a regular training programme).

The second priority in this Level 3 is the *Share Values* sub-module in which the *LSS Project Manager* dimension has been identified as the most serious problem where a proper selection of projects' managers must take into consideration certain levels of leadership competencies' requirements to achieve the benchmark standard.

Lastly, the second priority in Level 4 is the *Administrative* sub-module that indicates a critical problematic area in the *Operations Budget Compliance* dimension due to not achieving the British Standard of budget compliance in total preventive maintenance cost with respect to total maintenance cost (target = 15%–18%).

Furthermore, for Priority 2, Figure 7.14 shows in detail the KB System prioritised audit trail which can be used to assist with decision making and to develop an action plan for TTC across the analysed organisation Levels. In this case, it is recommended to start with the *Programmes* dimension in Level 2, followed by the *LSS Project Manager* dimension in Level 3, and completed by the *Operations Budget Compliance* dimension in Level 4.

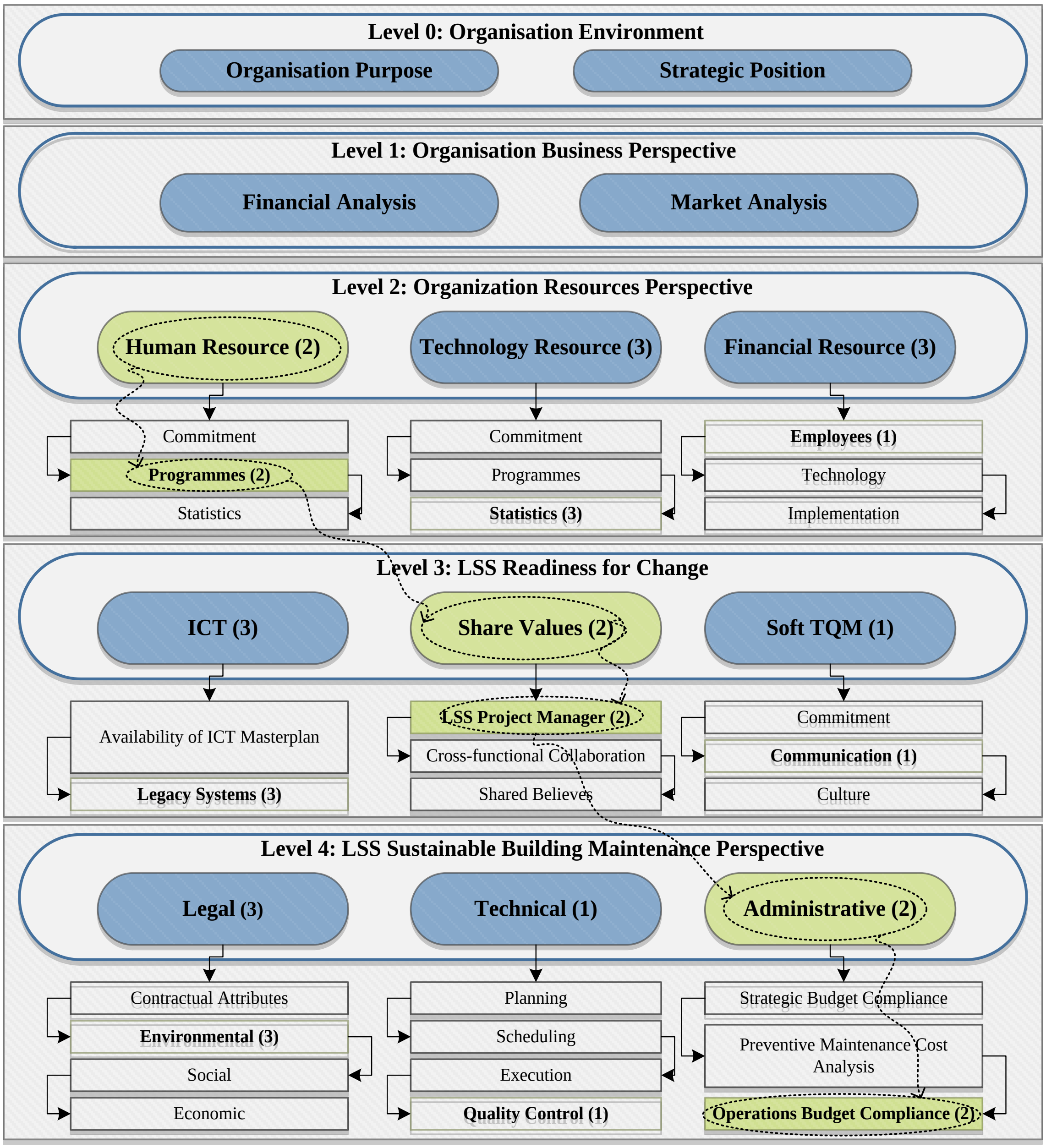


Figure 7. 14 Priority 2 Organisation TTC: Developed Lean6-SBM Framework

In terms of the KB System, AHP Priority 2 and the audit trail of the rules, Figure 7.15 illustrates the key sub-modules, dimensions, and priority rules across all levels for improvements to achieve benchmark standards at TTC. Again, for the sake of brevity, only PC-1 and PC-2 are shown. However, the KB System shows an audit trail for all of the rule-based PCs identified and which need action.

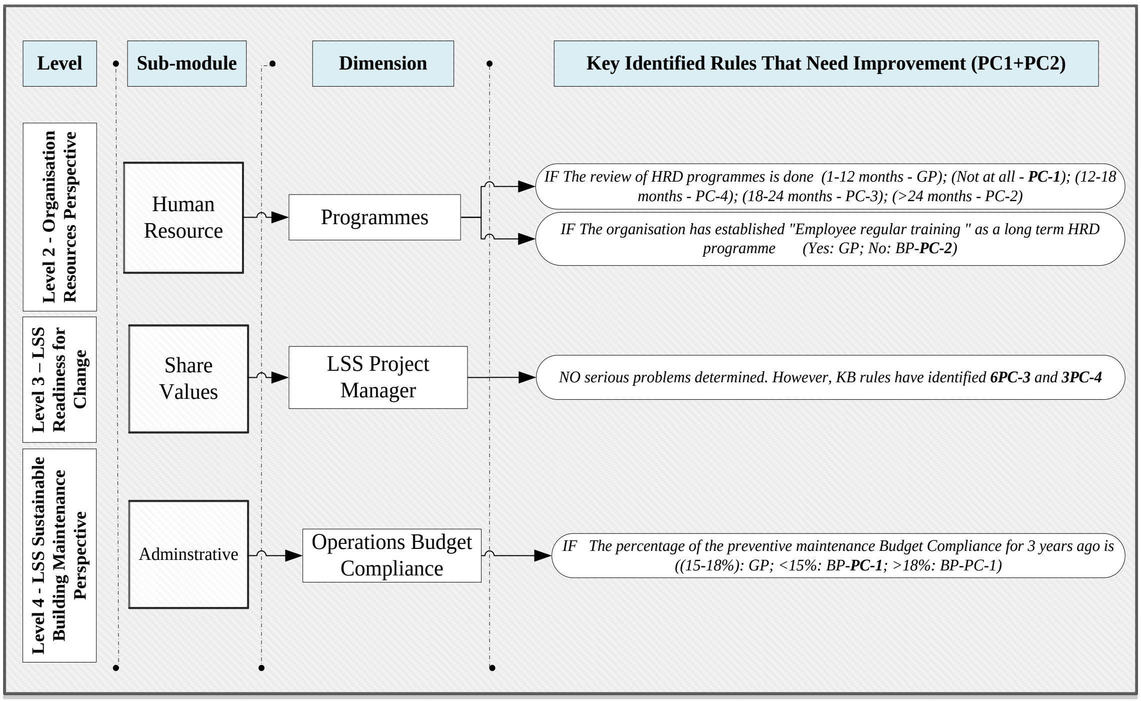


Figure 7. 15 Priority 2 Improvements Actions Identified by KB Lean6-SBM System for Organisation TTC

Figure 7.15 shows that HRD programmes are an essential step to achieve competitive advantages. Also, it can be noted that the KB System has not identified any critical issue for Priority 2 improvements in the *LSS Project Manager* dimension. However, as was the case with BEC, there are still some BPs that have been detected (6 PC-3 and 3 PC-4) by the AHP aspect which might not cause any problem in the short term. Although, neglecting the same may cascade to future leadership implications. This has been created by having an unbalanced level of competencies which might lead to improper project management.

7.5.1.3 Priority 3 Improvements for Organisation TTC

The developed Lean6-SBM framework shown in Figure 7.16 illustrates a Priority 3 visual improvement roadmap for TTC prioritised by the KB-AHP-GAP System. In Level 2, the *Technology Resource* sub-module was identified as Priority 3 in terms of improvement where the *Statistics* dimension is the most problematic (having a low level of ideas discussed over suggested, and implemented over accepted with respect to technology improvements for the last three years).

The third priority in Level 3 is the *ICT* sub-module, which is dominated by the dimension of *Legacy Systems* that indicates a gap in technical systems' support (i.e. SLA), and fulfilment of business requirements.

Lastly, for Level 4, the KB System has determined a Priority 3 in the *Legal* sub-module, in which the *Environmental* dimension dominates the other sustainability aspects by having serious problems in the areas of environmental policy, and controlling maintenance wastes.

Thus, for Priority 3, Figure 7.16 demonstrates in detail the KB System prioritised audit trail which can be used to assist with decision making and to develop an action plan for TTC across the analysed organisation Levels (Level 2–Level 4). In this case, it is recommended to start with the *Statistics* dimension in Level 2, followed by the *Legacy Systems* dimension in Level 3, and completed by the *Environmental* dimension in Level 4.

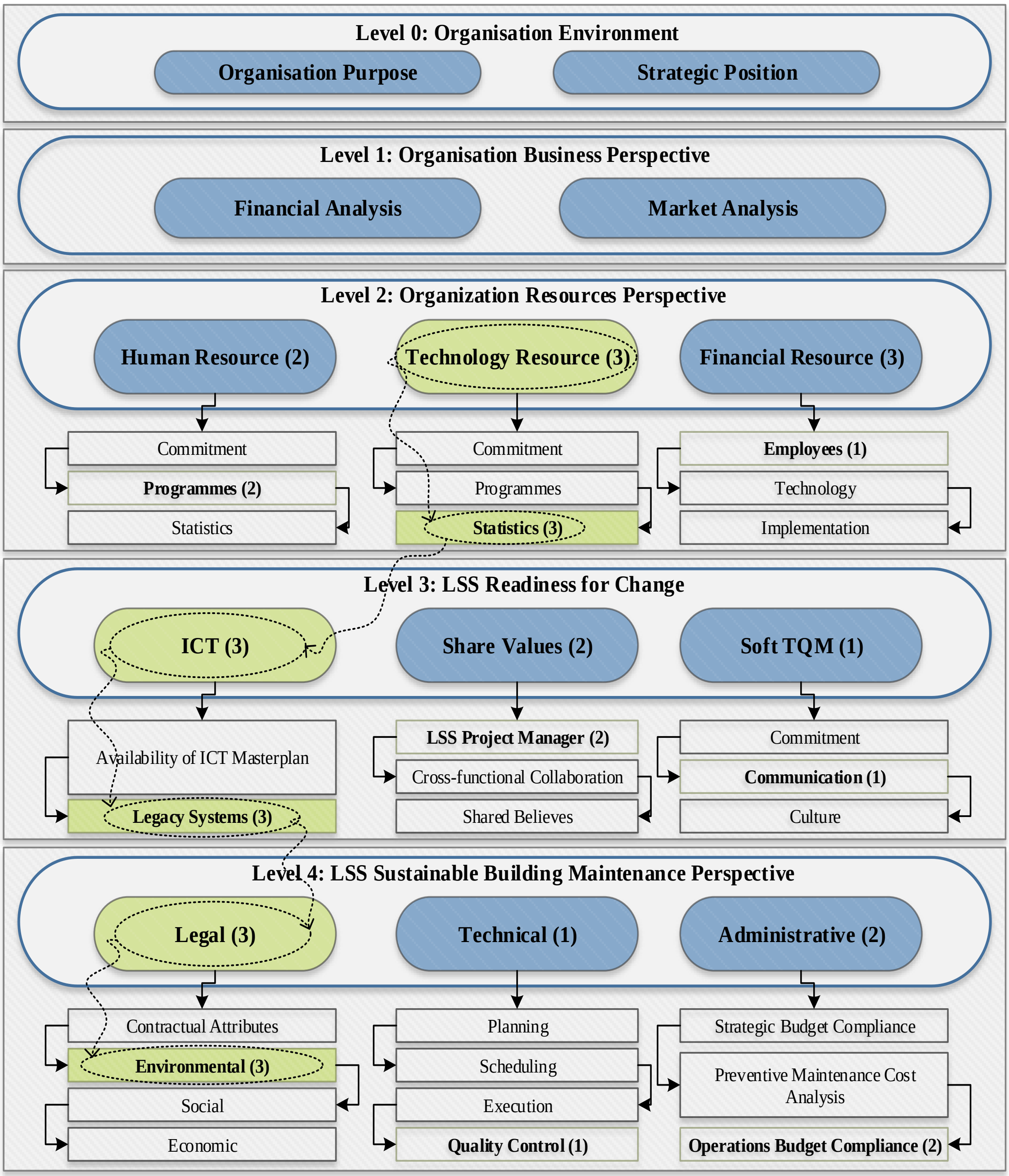


Figure 7. 16 Priority 3 Organisation TTC: Developed Lean6-SBM Framework

With regards to the KB System, AHP Priority 3 and the audit trail of the rules, Figure 7.17 illustrates the key sub-modules, dimensions, and priority rules across all levels for improvements to achieve benchmark standards at TTC.

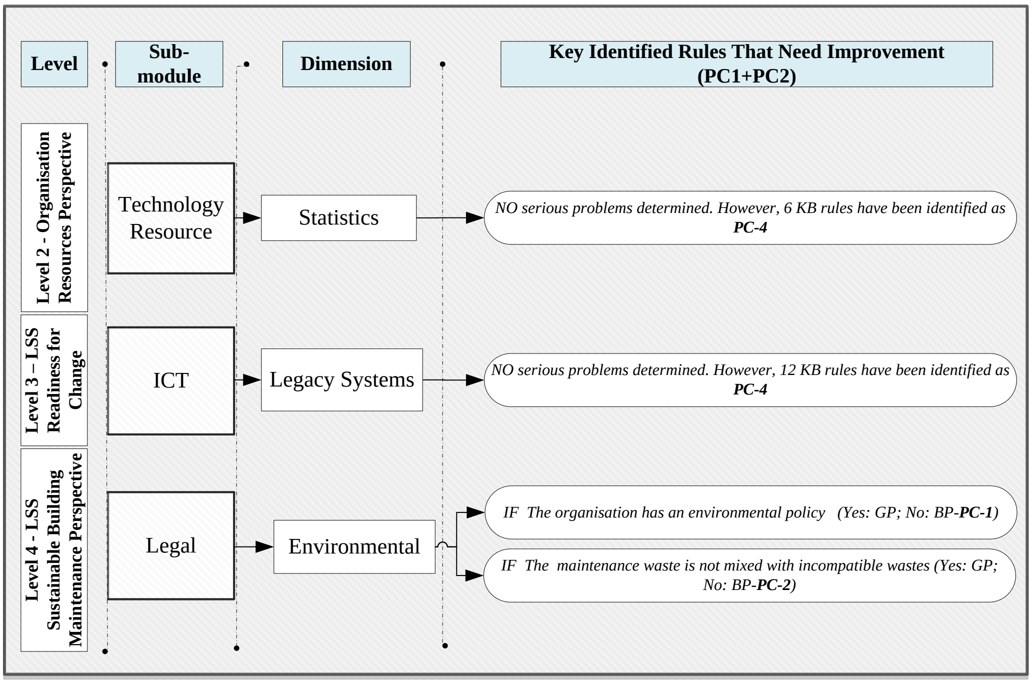


Figure 7. 17 Priority 3 Improvements Actions Identified by KB Lean6-SBM System for Organisation TTC

Again, for the sake of brevity, only PC-1 and PC-2 are shown. Nevertheless, the KB System shows an audit trail for all of the rule-based PCs identified and which need action. In spite of the good efforts towards sustainability, the KB System has identified that TTC is practising a critical activity in which maintenance waste is mixed with other types of waste. This might occur due to unavailability of waste classification guidance and technical instructions. In essence, it is essential for TTC to start filling in these gaps in order to achieve the Lean6-SBM standard of sustainability in the work environment.

7.5.2 Review of the Organisation TTC Validation Process

Again, the validation output of the KB Lean6-SBM model at TTC has proven the system capability in providing a reliable and flexible integration between the KB, GAP and AHP. The KB System has achieved the main research objectives by identifying the prioritised actions for improvements in each level of the organisation structure. It has also shown the audit trail of the KB rules along with the demonstration of key rules in each Level.

For Priority 1 *Strategic Decision Levels*, it has been identified that TTC should focus on the sub-module *Financial Resource* (*Employees* dimension) and the sub-module *Soft TQM* (*Communication* dimension), whereas for Priority 1

Operational Decision Levels, the KB System has recommended concentration on the *Technical* sub-module (*Quality Control* dimension).

In terms of Priority 2 *Strategic Decision Levels*, the KB System has identified that TTC should focus on the sub-module *Human Resource* (*Programmes* dimension) and the sub-module *Share Values* (*LSS Project Manager* dimension). In the meantime, for Priority 2 *Operational Decision Levels*, the system has suggested improvement of the *Administrative* sub-module (*Operation Budget Compliance* dimension).

Finally, for Priority 3 *Strategic Decision Levels,* the KB System has determined that TTC has to rectify the sub-module *Technology Resource* (*Statistics* dimension) and the sub-module *ICT* (*Legacy Systems* dimension), meanwhile for Priority 3 *Operational Decision Levels*, the system has recommended to focus on the *Legal* sub-module (*Environmental* dimension).

7.6 Organisation AFHES: Level 5 – DMAIC Implementation

The *Level 5: DMAIC Implementation* of the Lean6-SBM model consists of two sub-modules: *Pre-implementation* and *Post-implementation* as shown in Figure 7.18. This Level is exclusively designed to evaluate SBM organisations that have already applied LSS projects.

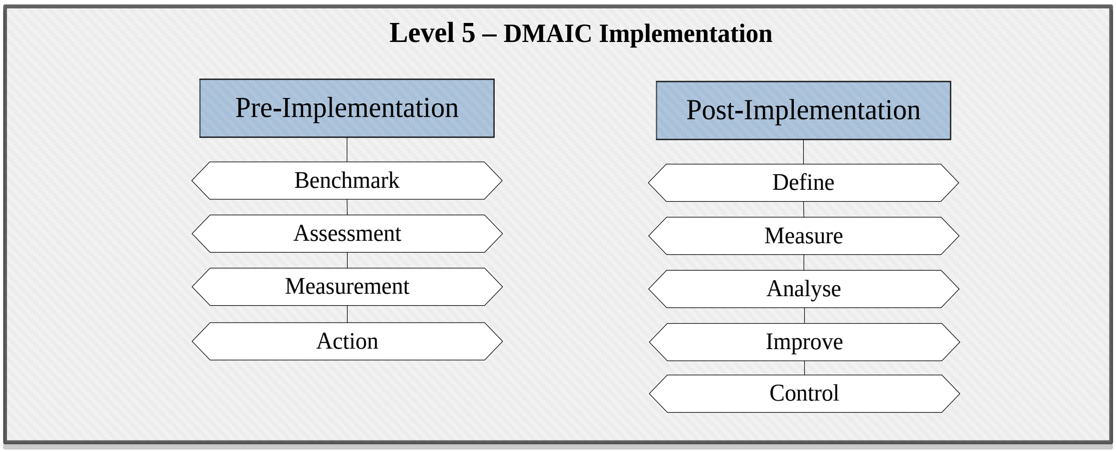


Figure 7. 18 Organisation AFHES: Level 5 – DMAIC Implementation

As discussed in Chapter 6, the *Pre-implementation* sub-module will be evaluated based on four dimensions: *Benchmark, Assessment, Measurement*, and

Action whereas the *Post-implementation* sub-module will cover the areas of *Define*, *Measure*, *Analyse*, *Improve*, and *Control*.

Table 7.23 summarised the AFHES GAP analysis results of the *Level 5: DMAIC Implementation* perspective. A total of 97 KB rules have been triggered in this module and out of these, the model analysis has categorised 52 as GPs and 44 have been categorised as BPs. The 44 bad points are classified into different problem categories (24 PC-1, 6 PC-2, 9 PC-3, and 5 PC-4) where they represent the activities that need to be rectified to achieve the desired Lean6-SBM benchmark.

In the *Pre-implementation* sub-module, the KB Lean6-SBM has identified 22 GPs out of 43 KB rules triggered. However, 21 KB rules were not met, indicating a gap in pre-requisites for achieving benchmark. A further study has indicated that the most problematic area is in the dimension of *Benchmark* with 7 BPs (7 PC-1), followed by the dimension of *Action* with 10 BPs (of which 8PC-1 and 1 PC-2).

In the dimension of *Benchmark*, the KB Lean6-SBM System has validated key risky aspects that need to be tackled with a lot of attention from AFHES. These comprise working towards developing an LSS culture and adopting a qualified LSS trainer to ensure continuous retraining of selected employees. Missing a clear vision and roadmap on creating a culture change has cascaded to a major failure in other MODES departments. Hence, it is recommended for the decision maker at AFHES to validate their current situation using the *LSS Readiness for Change* module.

Investigating the Action dimension at AFHES has exposed the unfamiliarity of the DMAIC project team with some basic and very important LSS tools and techniques. For the project selected by the process owner (Investigating frequent pump failures) at AFHES, it was significantly required by the project team to be fully trained in using VSM and MSA techniques before attempting to be engaged in DMAIC process improvement.

Efficient use of the VSM in this project allows the team to distinguish between added value and non-added value steps initially during a new pump installation and at the PM stage. In addition, it allows them to visualise the lead time in each part of the process. On the other hand, MSA provides the real data-measuring platform before the failure occurs. This includes investigating error percentages in measurements (e.g. ampere, voltage, vibration) using parameters like repeatability (one person taking multiple measurements using the same technique and device with the same item), and reproducibility (two or more people taking measurements using the same technique and device with the same item).

Table 7. 23 GAP analysis results of the Organisation AFHES: Level 5 – DMAIC Implementation

Level 5: *DMAIC Implementation* GAP Analysis: AFHES

Sub-module		Dimensions	No. KB rules	Good Point	Bad Point	Problem Category				
						1	2	3	4	5
DMAIC Implementation	**Pre-Implementation**	Benchmark	12	5	7	7	0	0	0	0
		Assessment	6	2	4	0	1	2	1	0
		Measurement	2	2	0	0	0	0	0	0
		Action	23	13	10	8	1	1	0	0
	Sub-total		**43**	**22**	**21**	**15**	**2**	**3**	**1**	**0**
	Post-Implementation	Define	15	11	4	2	2	0	0	0
		Measure	8	3	5	2	0	2	1	0
		Analyse	11	5	6	1	1	4	0	0
		Improve	9	8	1	1	0	0	0	0
		Control	10	3	7	3	1	0	3	0
	Sub-total		**53**	**30**	**23**	**9**	**4**	**6**	**4**	**0**
Total			**97**	**52**	**44**	**24**	**6**	**9**	**5**	**0**

In the *Post-implementation* sub-module, out of 53 KB rules triggered, 30 GPs were recorded for AFHES. However, 23 KB rules were declared as BPs, indicating a gap in pre-requisites for achieving benchmark. A further investigation by the system revealed that the key problematic area is in the dimension of *Control* (7 BPs of which 3 PC-1 and 1 PC-2). From the fact that has been explored in *Pre-implementation*, which concerns the missing aspect of VSM, the flow has affected the *Control* phase in which the initial VSM has to be optimised to convert the current state map into a future state map. In essence, that was an expected issue due to non-availability of a manageable documentation process and further response action plan.

The above GAP analysis has been used by the KB Lean6-SBM model to produce the AHP analysis. This step is very important as it determines which aspects should prioritise improvements for future projects’ implementation. The integrated AHP will start the analysis by determining the values of priority vectors (PV) in each sub-module. For the sub-modules *Pre-implementation*, and *Post-*

implementation, the PV values of each dimension have been calculated as represented in Tables 7.24 and 7.25 respectively.

Table 7. 24 Pre-implementation AHP analysis with PV for Organisation AFHES

Pre-Implementation	Benchmark	Assessment	Measurement	Action	P.V
Benchmark	1	5	7	3	**0.55**
Assessment	1/5	1	4	1/3	0.13
Measurement	1/7	1/4	1	1/5	0.05
Action	1/3	3	5	1	0.26

Table 7.24 shows the PV values in the *Pre-implementation* sub-module. The values are **0.55** for *Benchmark*, 0.13 for *Assessment,* 0.05 for *Measurement,* and 0.26 for *Action*. This means that focusing on this sub-module, AFHES's priority is to rectify the dimension of *Benchmark* before attempting the other dimensions*.* The analysis has indicated that the major non-compliance is in standardisation and adopting a qualified LSS trainer.

Table 7. 25 Post-implementation AHP analysis with PV for Organisation AFHES

Post-Implementation	Define	Measure	Analyse	Improve	Control	P.V
Define	1	1/3	1/2	2	1/4	0.10
Measure	3	1	3	4	1/2	0.28
Analyse	2	1/3	1	3	1/3	0.15
Improve	1/2	1/4	1/3	1	1/5	0.06
Control	4	2	3	5	1	**0.40**

Table 7.25 indicates the PV values for the *Post-implementation* sub-module. The PV values for *Define*, *Measure*, *Analyse*, *Improve*, and *Control* are 0.10, 0.28, 0.15, 0.06, and **0.40** respectively. Therefore, the priority for AFHES to focus on in this sub-module is to improve the dimension *Control* before attempting the dimensions *Measure*, *Analyse, Define,* and *Improve.* This was highlighted due to

non-consideration of the development of manageable documentation and a response control plan.

7.7 Organisation AFHES: Validation Discussion of KB Lean6-SBM Model

This section will summarise the results analysis at AFHES based on the applied validation process as discussed earlier in Section 7.3.

7.7.1 Summarised KB Lean6-SBM Output for Organisation AFHES

Based on the KB Lean6-SBM model analysis of Level 5 in Section 7.3, Table 7.26 illustrates the summarised results for AFHES. 96 KB rules were triggered in these sub-modules. The analysis shows that 44 BPs were identified by the model based on the AFHES user response, which demonstrates the overall organisation performance of about 45.8% lower than the designed benchmark standard (a high risk of LSS implementation). It can be seen from Table 7.26 that AFHES has 31.3% of the BPs as major problematic areas and 14.5% of the BPs as minor problems. The detailed breakdown of the sub-modules' BPs percentages can be highlighted in ratios (serious:unserious) as 48.8% (39.5:9.3) and 43.4% (24.5:18.9) respectively.

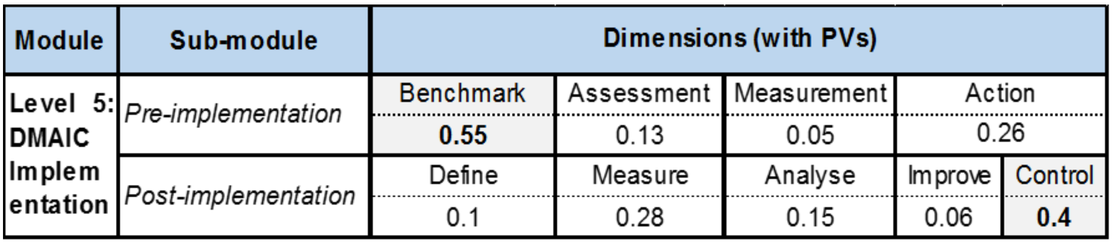
Table 7. 26 Summary of GAP Analysis Results for Organisation AFHES

Level 5: DMAIC Implementation GAP Analysis: AFHES										
Module	Sub-module	Dimension	No. KB rules	Good Point	Bad Point	Problem Category				
						1	2	3	4	5
Level 5: DMAIC Implementation	**Pre-Implementation**	Benchmark	12	5	7	7	0	0	0	0
		Assessment	6	2	4	0	1	2	1	0
		Measurement	2	2	0	0	0	0	0	0
		Action	23	13	10	8	1	1	0	0
	Sub-total		**43**	**22**	**21**	**15**	**2**	**3**	**1**	**0**
	Percentage (%)			**51.2**	**48.8**	**39.5**		**9.3**		
	Post-Implementation	Define	15	11	4	2	2	0	0	0
		Measure	8	3	5	2	0	2	1	0
		Analyse	11	5	6	1	1	4	0	0
		Improve	9	8	1	1	0	0	0	0
		Control	10	3	7	3	1	0	3	0
	Sub-total		**53**	**30**	**23**	**9**	**4**	**6**	**4**	**0**
	Percentage (%)			**56.6**	**43.4**	**24.5**		**18.9**		
Total			**96**	**52**	**44**	**24**	**6**	**9**	**5**	**0**
Percentage (%)				**54.2**	**45.8**	**31.3**		**14.5**		

In the AFHES *Pre-implementation* sub-module, the most critical area was identified in the dimension of *Benchmark.* The gap has been declared in missing a clear vision and LSS change management roadmap. Therefore, the KB Lean6-SBM System has recommended a further readiness test using the *Level 3: LSS Readiness for Change* module.

In the *Post-implementation* sub-module, the key problematic area was in the dimension of *Control*. The missing aspect of familiarity with LSS tools/techniques in the *Pre-implementation* sub-module, has affected the flow of the *Control* phase along with the loss of the documentation process and further response action plan.

Table 7. 27 Summary of AHP-PV values for Organisation AFHES



Module	**Sub-module**	**Dimensions (with PVs)**				
Level 5: DMAIC Implementation	*Pre-implementation*	Benchmark	Assessment	Measurement	Action	
		0.55	0.13	0.05	0.26	
	Post-implementation	Define	Measure	Analyse	Improve	Control
		0.1	0.28	0.15	0.06	**0.4**

The KB Lean6-SBM is embedded with AHP to support AFHES in prioritising their improvements' decisions by facilitating the PV values for each aspect of the module. Table 7.27 illustrates the PV values for each aspect within the sub-modules (*Pre-implementation* and *Post-implementation*). Although the analysis and summary of this module do not require pairwise comparisons between sub-modules and with other Levels as the benefit from the results/output is to evaluate executed/implemented LSS projects in a SBM environment.

7.7.1.1 Pre-Implementation Improvements for Organisation AFHES

Figure 7.19 visualises the areas that need future concentration and rectification by the AFHES before attempting to implement any LSS project. It can be treated in a step-by-step prioritised manner as shown below, bearing in mind the immediate actions to be taken for the most serious problems which represent 39.5% of the total BPs in the *Pre-implementation* sub-module.

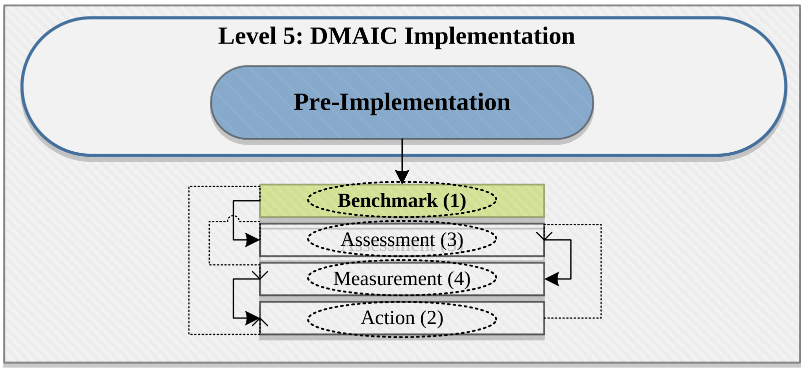


Figure 7. 19 Organisation AFHES: Developed Lean6-SBM Implementation Framework

The developed DMAIC framework shown in Figure 7.19 illustrates a (Priority 1–Priority 4) visual improvement roadmap for AFHES prioritised by the KB-AHP-GAP System. The AHP aspect of the KB System has identified the list of priorities in *Pre-implementation* that AFHES should improve. Within this perspective, the dimension *Benchmark* has been identified as the key aspect followed by *Action, Assessment*, and *Measurement* dimensions (in descending priority order).

In terms of the KB System, AHP Priority scheme and the audit trail of the rules, Figure 7.20 illustrates the key dimensions, and priority rules across the *Pre-implementation* sub-module for improvements to achieve benchmark standards at the AFHES. For the sake of brevity, only PC-1 and PC-2 are shown. However, the KB System shows an audit trail for all of the rule-based PCs identified and which need action.

In the dimension of *Benchmark,* the gap was identified in having no clear vision towards LSS standards. In addition, the organisation environment was not ready for the LSS implementation and cultural change. Last, but not least, AFHES has not adopted a qualified LSS trainer to coach the project team and ensure their readiness before the implementation.

With regards to the dimension of *Action*, the KB System has determined a critical issue with the familiarity of using LSS tools/techniques (i.e. MSA, Pareto Chart, Control Chart, COPQ, and QFD). These are representing the fundamentals of an LSS approach. Furthermore, AFHES has not evaluated the involvement of these tools/techniques in previous LSS projects, so as to capture lessons learnt and avoid repetitive failures.

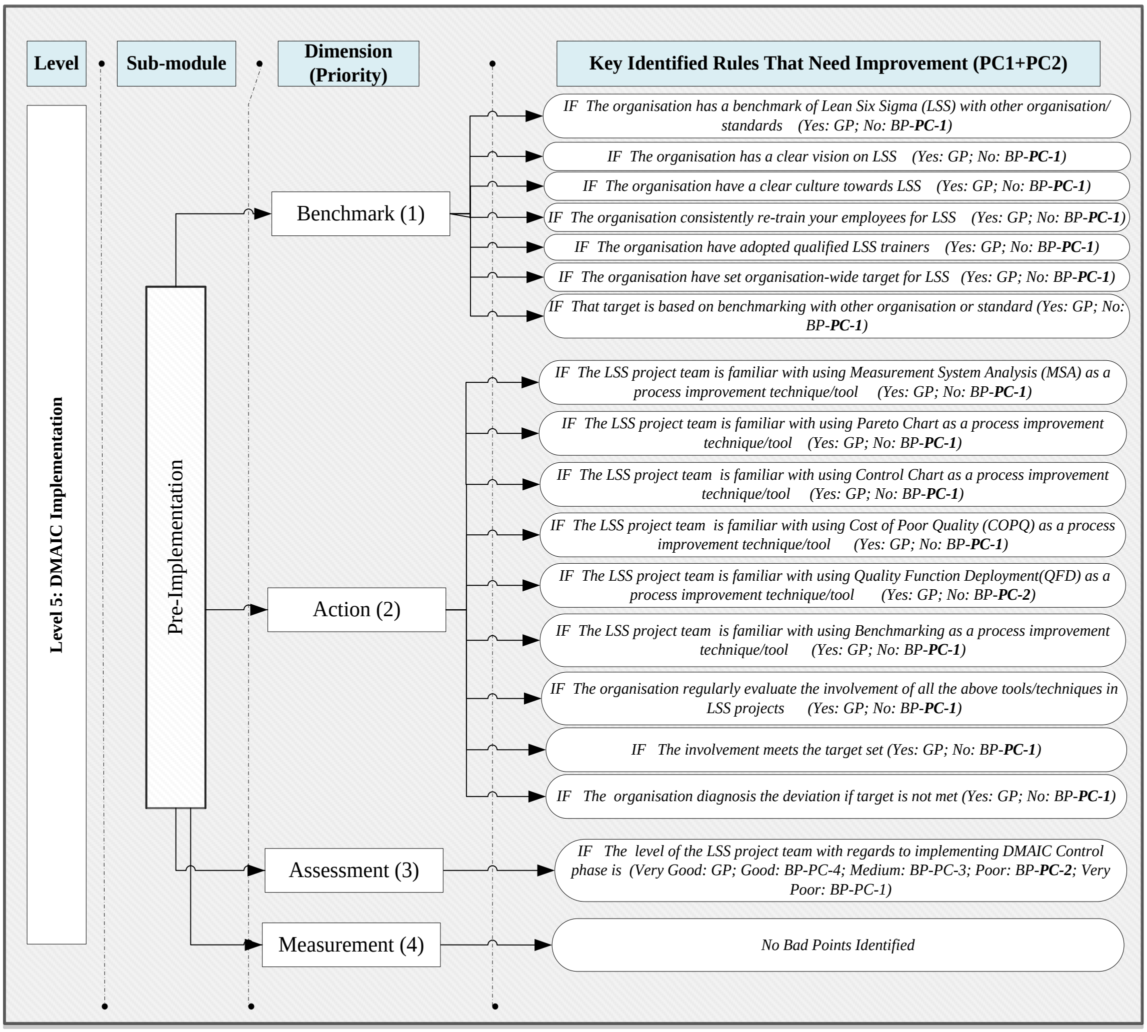


Figure 7. 20 Pre-Implementation Priorities' Improvements Actions Identified by KB System for Organisation AFHES

Finally, the KB System has identified one major problem in the dimension of *Assessment* (in which the level of know-how for implementing the DMAIC *Control* phase is below the benchmark standard). In fact, this assessment is based on the user/participant experience. However, further assessment for the *Post-implementation* sub-module may prove or show contradiction in this regard.

7.7.1.2 Post-Implementation Improvements for Organisation AFHES

In terms of *Post-implementation*, Figure 7.21 shows the areas that need improvements and upgrading skills by AFHES before attempting to implement any LSS DMAIC project. It can be treated in a step-by-step prioritised manner as shown below, bearing in mind the immediate actions to be taken for the most serious problems which represent 24.5% of the total BPs in the *Post-implementation* sub-module. Although it is suggested that AFHES can go into a much deeper assessment by using the KB Lean6-SBM (*Level 2–Level 4*) prior to any further implementation.

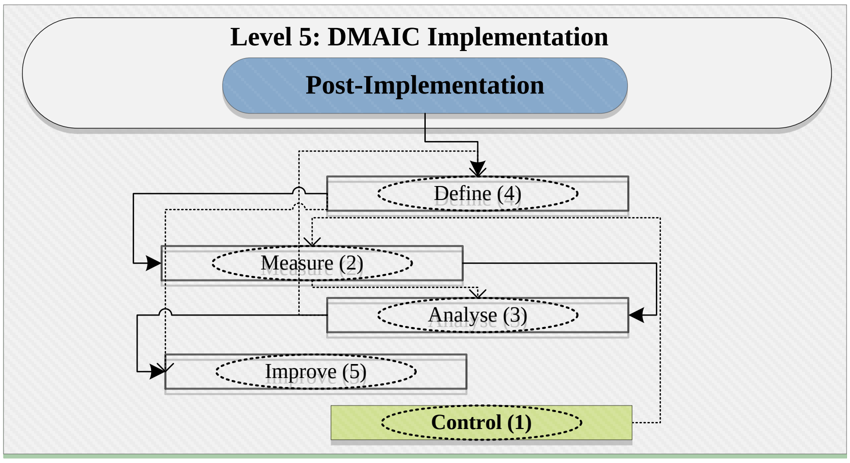
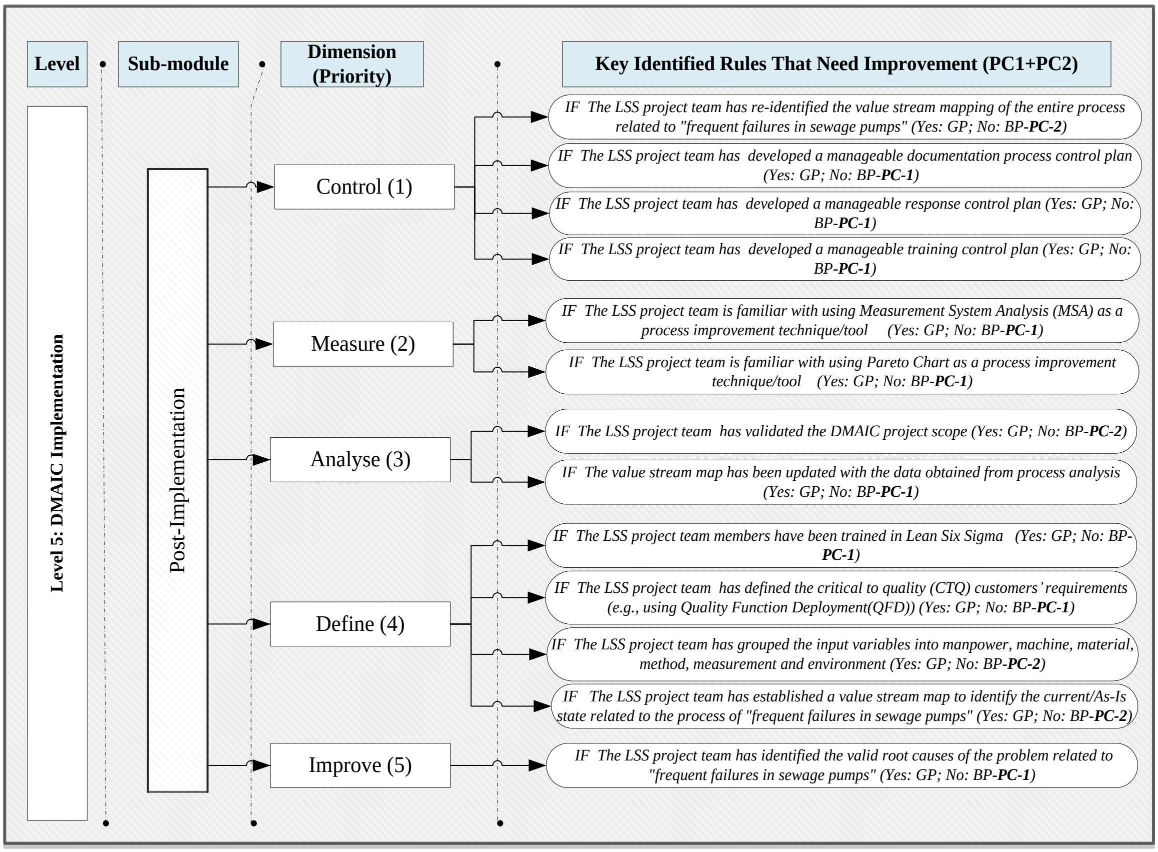


Figure 7. 21 Organisation AFHES: Developed Lean6-SBM Implementation Framework

In terms of the KB System, AHP Priority scheme and the audit trail of the rules, Figure 7.22 illustrates the key dimensions, and priority rules across *Post-implementation* for improvements to achieve benchmark standards at AFHES. Again, for the sake of brevity, only PC-1 and PC-2 are shown. However, the KB System shows an audit trail for all of the rule-based PCs identified and which need action.

Figure 7.22 has proved that Priority 1 of the AFHES DMAIC cycle is the *Control* dimension in which it shows the lowest level of know-how competencies among the AFHES LSS project team members. In this dimension, the organisation has to be aware of the importance of re-identifying and updating the VSM of the process. Besides, it must create manageable documentation of response and training plans which will assist in sustaining the recommended solutions to obtain future Lean perfection.

For the *Measure* dimension (Priority 2), it is essential for the LSS project manager to ensure that the team members are familiar with adopting the MSA technique. The team should also use the Pareto Chart as one of the best start-up tools in LSS – used to identify major variables from minor ones. On the other hand, Priority 3 of the DMAIC cycle is represented by the dimension of *Analyse*. In this phase, the KB System has identified that AFHES did not apply any hypothesis test to the initial measurement results which leads to a serious gap in validating the DMAIC project scope. In addition, the unfamiliarity with VSM has been cascaded to this stage as it needs continuous updating.



*IF The LSS project team has re-identified the value stream mapping of the entire process related to "frequent failures in sewage pumps" (Yes: GP; No: BP-**PC-2**)*

*IF The LSS project team has developed a manageable documentation process control plan (Yes: GP; No: BP-**PC-1**)*

*IF The LSS project team has developed a manageable response control plan (Yes: GP; No: BP-**PC-1**)*

*IF The LSS project team has developed a manageable training control plan (Yes: GP; No: BP-**PC-1**)*

*IF The LSS project team is familiar with using Measurement System Analysis (MSA) as a process improvement technique/tool (Yes: GP; No: BP-**PC-1**)*

*IF The LSS project team is familiar with using Pareto Chart as a process improvement technique/tool (Yes: GP; No: BP-**PC-1**)*

*IF The LSS project team has validated the DMAIC project scope (Yes: GP; No: BP-**PC-2**)*

*IF The value stream map has been updated with the data obtained from process analysis (Yes: GP; No: BP-**PC-1**)*

*IF The LSS project team members have been trained in Lean Six Sigma (Yes: GP; No: BP-**PC-1**)*

*IF The LSS project team has defined the critical to quality (CTQ) customers' requirements (e.g., using Quality Function Deployment(QFD)) (Yes: GP; No: BP-**PC-1**)*

*IF The LSS project team has grouped the input variables into manpower, machine, material, method, measurement and environment (Yes: GP; No: BP-**PC-2**)*

*IF The LSS project team has established a value stream map to identify the current/As-Is state related to the process of "frequent failures in sewage pumps" (Yes: GP; No: BP-**PC-2**)*

*IF The LSS project team has identified the valid root causes of the problem related to "frequent failures in sewage pumps" (Yes: GP; No: BP-**PC-1**)*

Figure 7. 22 Post-Implementation Priorities' Improvements Actions Identified by KB System for Organisation AFHES

The *Define* dimension comes in Priority 4 of the DMAIC framework improvements. The system has identified that the LSS team members have not been fully trained in LSS. This has caused unprofessional completion of the *Define* phase of the DMAIC cycle in which it implies expected failures in other phases. Thus, it can be noticed from the *Improve* dimension, that the LSS project team has failed to identify the critical root cause (of the frequent failures in sewage pumps) as a result of the previous misleading approach.

7.7.2 Review of the Organisation AFHES Validation Process

As concluded in the validation process of Level 2 to Level 4, the validation output of the KB Lean6-SBM model (Level 5) at AFHES has also demonstrated the system capability in providing a reliable and flexible integration between the KB, GAP, and AHP. The KB System has achieved the main research objective in identifying the prioritised actions for improvements in Level 5 of *DMAIC Implementation*. It has also shown the audit trail of the KB rules along with the demonstration of key rules in each dimension.

The KB System has identified the priorities for improvements in *Pre-implementation* that should start with the *Benchmark* dimension, followed by the dimensions of *Action, Assessment*, and *Measurement* respectively. Whereas in *Post-implementation*, the system has determined Priority 1 in *Control* followed by the dimensions of *Measure*, *Analyse*, *Define*, and *Improve* respectively.

The *DMAIC Implementation* Level improvements action plan can be treated in a step- by-step (prioritised) manner or in a pre-requisite sequence as recommended for the *Post-implementation* dimension. However, it is suggested that AFHES could adopt a more in-depth organisation assessment by using the KB Lean6-SBM (*Level 2–Level 4*) prior to any further LSS implementation.

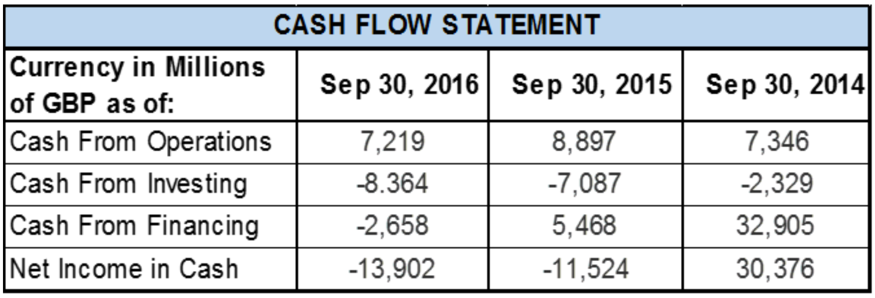
7.8 Validation of KB Lean6-SBM Model Using a Case Study from Literature

As described in Section 7.3, there was difficulty in finding the data required to complete the validation process of the KB Lean6-SBM, specifically in the sub-module of *Financial Analysis* (*Level 1*). Therefore, it was decided to conduct this part of the validation through a case study from the literature. Hence, an extensive review of published data has been carried out targeting facilities management companies. In this study, **Servest Group Limited** was selected based on its expertise in the field of sustainable facilities management and PM services (Servest, 2016).

7.8.1 Populating the Financial Analysis Sub-Module

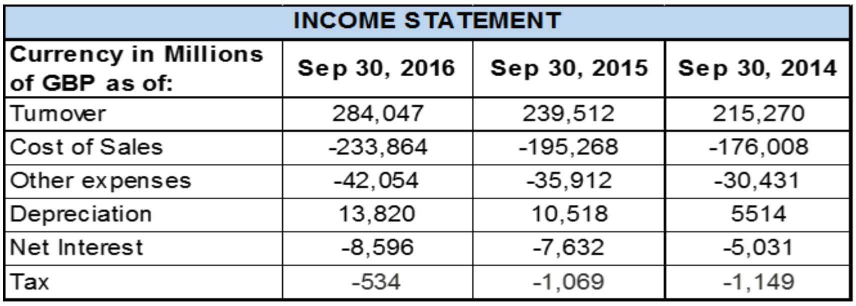
According to Servest (2015) integrated report of 2014, Servest Group Limited was established in 1997. It provides facilities management solutions at more than 24,000 sites throughout the United Kingdom and in 10 African countries, targeting a number of clients, exceeding 6,500. The Servest facilities management platform is playing the role of both hard (e.g. building maintenance) and soft (e.g. waste management) services within a sustainable environment. Servest became one of the top five facilities management providers in the UK with a total of 38,000 employees as of 2016 (Aldalou, 2016). This study uses Servest (2015) and *fame* (2017) financial reports for the validation process of the *Financial Analysis* sub-module. The data related to the financial analysis are presented in Table 7.28 (*Cash Flow Statement*), Table 7.29 (*Income Statement*), and Table 7.30 (*Balance Sheet*).

Table 7. 28 Cash Flow Statement of Organisation Servest



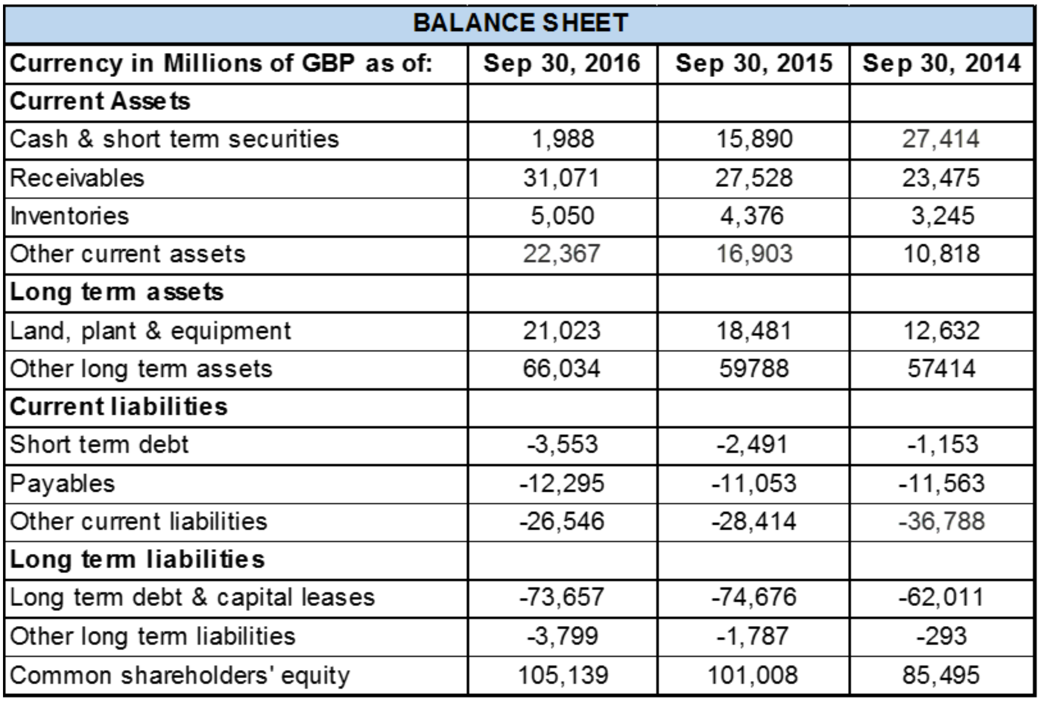
CASH FLOW STATEMENT			
Currency in Millions of GBP as of:	**Sep 30, 2016**	**Sep 30, 2015**	**Sep 30, 2014**
Cash From Operations	7,219	8,897	7,346
Cash From Investing	-8.364	-7,087	-2,329
Cash From Financing	-2,658	5,468	32,905
Net Income in Cash	-13,902	-11,524	30,376

Table 7. 29 Income Statement of Organisation Servest



INCOME STATEMENT			
Currency in Millions of GBP as of:	**Sep 30, 2016**	**Sep 30, 2015**	**Sep 30, 2014**
Turnover	284,047	239,512	215,270
Cost of Sales	-233,864	-195,268	-176,008
Other expenses	-42,054	-35,912	-30,431
Depreciation	13,820	10,518	5514
Net Interest	-8,596	-7,632	-5,031
Tax	-534	-1,069	-1,149

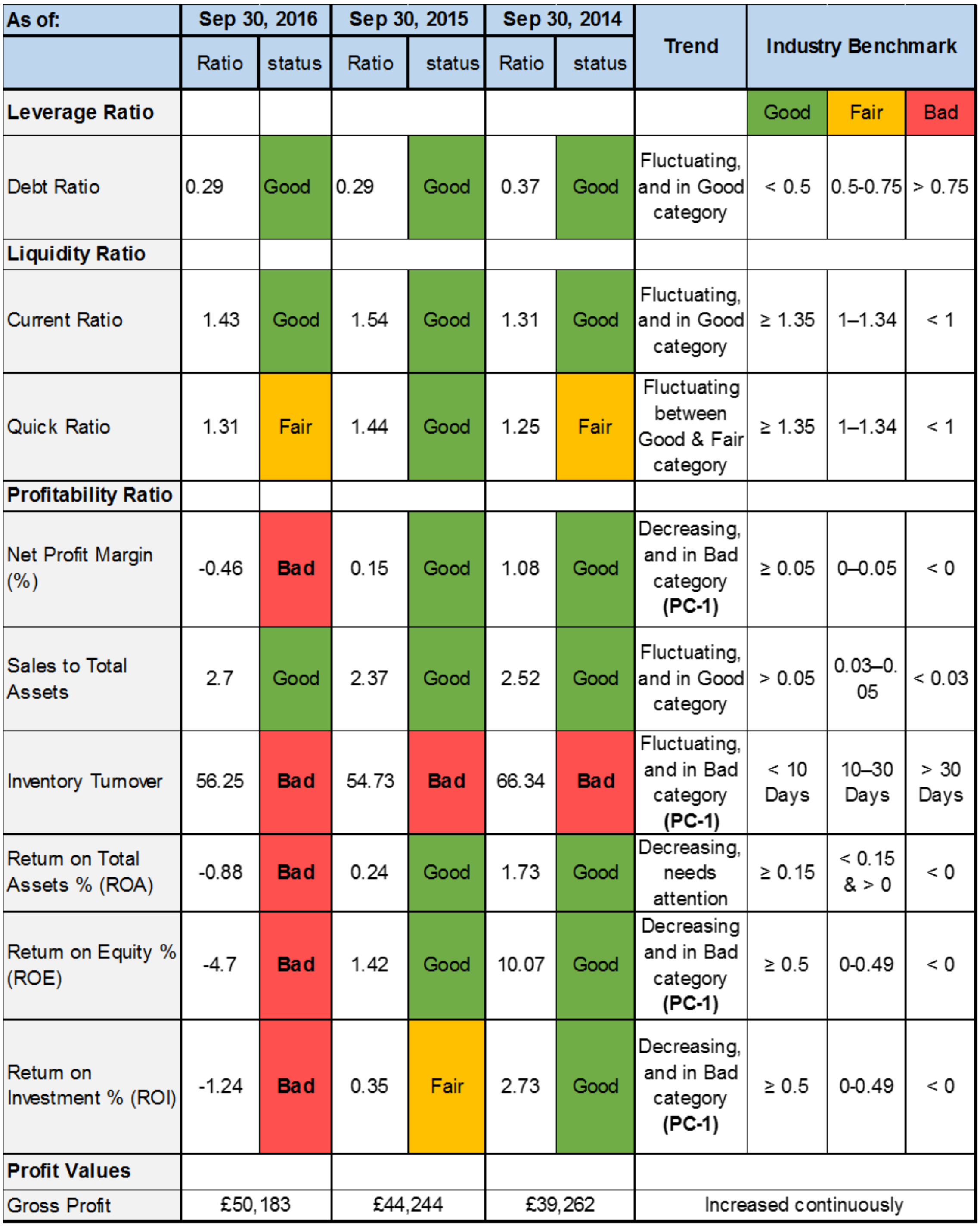
Table 7. 30 Balance Sheet of Organisation Servest



BALANCE SHEET			
Currency in Millions of GBP as of:	**Sep 30, 2016**	**Sep 30, 2015**	**Sep 30, 2014**
Current Assets			
Cash & short term securities	1,988	15,890	27,414
Receivables	31,071	27,528	23,475
Inventories	5,050	4,376	3,245
Other current assets	22,367	16,903	10,818
Long term assets			
Land, plant & equipment	21,023	18,481	12,632
Other long term assets	66,034	59788	57414
Current liabilities			
Short term debt	-3,553	-2,491	-1,153
Payables	-12,295	-11,053	-11,563
Other current liabilities	-26,546	-28,414	-36,788
Long term liabilities			
Long term debt & capital leases	-73,657	-74,676	-62,011
Other long term liabilities	-3,799	-1,787	-293
Common shareholders' equity	105,139	101,008	85,495

Based on the above input data, the KB Lean6-SBM model has used the rule based system to generate the output as shown in Table 7.31.

Table 7. 31 Output of Financial Analysis for Organisation Servest



As of:	**Sep 30, 2016**		**Sep 30, 2015**		**Sep 30, 2014**		**Trend**	**Industry Benchmark**		
	Ratio	status	Ratio	status	Ratio	status				
Leverage Ratio								Good	Fair	Bad
Debt Ratio	0.29	Good	0.29	Good	0.37	Good	Fluctuating, and in Good category	< 0.5	0.5-0.75	> 0.75
Liquidity Ratio										
Current Ratio	1.43	Good	1.54	Good	1.31	Good	Fluctuating, and in Good category	≥ 1.35	1–1.34	< 1
Quick Ratio	1.31	Fair	1.44	Good	1.25	Fair	Fluctuating between Good & Fair category	≥ 1.35	1–1.34	< 1
Profitability Ratio										
Net Profit Margin (%)	-0.46	**Bad**	0.15	Good	1.08	Good	Decreasing, and in Bad category **(PC-1)**	≥ 0.05	0–0.05	< 0
Sales to Total Assets	2.7	Good	2.37	Good	2.52	Good	Fluctuating, and in Good category	> 0.05	0.03–0.05	< 0.03
Inventory Turnover	56.25	**Bad**	54.73	**Bad**	66.34	**Bad**	Fluctuating, and in Bad category **(PC-1)**	< 10 Days	10–30 Days	> 30 Days
Return on Total Assets % (ROA)	-0.88	**Bad**	0.24	Good	1.73	Good	Decreasing, needs attention	≥ 0.15	< 0.15 & > 0	< 0
Return on Equity % (ROE)	-4.7	**Bad**	1.42	Good	10.07	Good	Decreasing and in Bad category **(PC-1)**	≥ 0.5	0-0.49	< 0
Return on Investment % (ROI)	-1.24	**Bad**	0.35	Fair	2.73	Good	Decreasing, and in Bad category **(PC-1)**	≥ 0.5	0-0.49	< 0
Profit Values										
Gross Profit	£50,183		£44,244		£39,262		Increased continuously			

Table 7.31 shows that in the *Leverage* category, the *Debt Ratio* of Servest has slightly decreased in 2015 where it was still in the *Good* category. In the *Liquidity* category, both *Current* and *Quick Ratios* have recorded a fluctuation, however, the *Current Ratio* has preserved the Good category as in 2016. With regards to the *Profitability Ratio,* the *Net Profit Margin* has entered the red caution line which reflects back the same scenario in *ROA.* Therefore, the KB system has

categorised both of them as serious problems (PC-1). Another remarkable point, which seems to be the consequence of such a dramatic decline in financial performance, is the *Inventory Turnover Ratio*. The analysis has identified that Servest has not practised a good benchmark standard in this category which triggers the need for immediate investigation of the strategy applied in supply chain management and therefore this ratio is classified as PC-1. The table also shows that *ROE* and *ROI* have a significant impairment from the year 2014 (10.07% and 2.73%) to the year 2016 (-4.70% and -1.42%) respectively which means they performed major issues rated as PC-1. However, the company's overall figure is still in the *Safe* category based on continuous increase in *Gross Profit*.

The KB Lean6-SBM System has indicated that Servest's cash flow fluctuated in the last three consecutive years. Although, the company has sustained a constant gross profit during the period which indicates good financial control. The KB Lean6-SBM suggests the trend of financial performance for Servest in the above mentioned period based on data provided from *fame* (2017). In essence, the KB Lean6-SBM System concluded that the financial performance of Servest has improved continuously over the last three consecutive years with a lot of attention needed to be taken in revising the aspect of *Inventory Turnover*.

7.8.2 Reflection on the Published Case Study Analysis

The *Financial Analysis* sub-module of the KB Lean-SBM System is the only sub-module that can be validated completely due to the availability of the data. This study has captured the financial data (i.e. the *Cash Flow, Income Statement*, and *Balance Sheet Statement*) of **Servest Group Limited,** published in *fame* (2017).

It has been proven that the KB Lean6-SBM System is giving the same results as indicated in the published financial data. The rules embedded in the *Financial Analysis* sub-module have converted that data into information. By assessing and comparing the level of financial performance of **Servest Group Limited** with the system industry financial benchmark (recommended by Leichter (2011); Smith and Mobley (2011)), the sub-module has converted that information into recommendations about the financial issues in the Company. Hence, the developed KB Lean6-SBM model is capable of helping such an organisation in the decision-making process.

7.9 Summary

This chapter demonstrates the results discussion of the validation process in industrial case studies. The logic behind applying the validation process is to show the capability of the KB Lean6-SBM model in optimising the decision-making process. The GAP and AHP analysis results were examined to identify the priorities between modules and sub-modules to achieve the benchmark performance improvements. Also, the process can confirm the capability of the developed model in giving valid decisions in a current situation.

The validation process has shown how the KB System helps to capture data related to the organisation’s performance. It has also shown how the rules are embedded in each module to establish relationships, and converts that data into information. Furthermore, the system proves to be capable in assessing and comparing the organisation’s level of performance with the Lean6-SBM benchmark, and proposing prioritised recommendations (in both strategic and operational levels) for current issues. The system has shown the ability to demonstrate the audit trail of the KB rules, key sub-modules, key dimensions, and the key priority rules across the framework *Levels*.

The developed KB Lean6-SBM model is validated through three real industrial case studies and one published case study. For the three industries, the companies BEC and TTC have participated in validating *Level 0* to *Level 4*, whereas the government organisation (AFHES) has been involved in validating *Level 5: DMAIC Implementation* of the model. On the other hand, the latest **Servest Group Limited** published reports were used to validate the *Financial Analysis* sub-module of the *Level 1: Organisation Business Perspective* module. The detailed discussion of the validation process was carried out for BEC and TTC (*Level 0*–*Level 4)* and AFHES (*Level 5*), however, for the sake of brevity the initial data analysis for TTC is presented in Appendix B.

For the validation of *Level 0* to *Level 4*, the KB System has recorded that BEC is practising 10.6% of serious problems out of all the issues (problem categories) identified. In TTC, the figure was less, where it counts 6% of the total bad points. On the other hand, the validation of *Level 5* revealed that the most serious problematic areas recorded in AFHES represent 31.7% of the total problems identified.

Based on BEC's validation process, the KB Lean6-SBM model has clearly shown the output of the organisation purpose (facilities management and maintenance services) and the output of the strategic position (medium size, integrated system organisation, good relationship with customers and suppliers, and capable for all PM activities) as a result of general data acquired at *Level 0: Organisation Environment Perspective Module*. In *Level 1: Organisation Business Perspective,* the validation has concluded a steady state trend of market share and competition in the last three years, whereas the financial part of this module has not been validated due to unavailability of data.

For BEC's **Priority 1**, in *Level 2*, the KB System has recommended that BEC has to focus on the *Commitment* dimension in the *Human Resource* sub-module. In *Level 3*, the KB System suggested that BEC needs to focus on the *Soft TQM* sub-module, especially in the dimension of *Communication*. For *Level 4*, the analysis shows that BEC has to concentrate on the dimension of *Quality Control* within the *Technical* sub-module. With regard to **Priority 2**, the system suggested that for improvement in *Level 2*, BEC should focus on the dimension of *Statistics* which belongs to the *Technology Resource* sub-module. That should be followed by the dimension of *LSS Project Manager* (*Share Values* sub-module), and completed with the dimension of *Operations Budget Compliance* within the *Administrative* sub-module. Finally, for **Priority 3**, BEC has to improve the sub-module *Financial Resource* (*Employees* dimension), followed by the dimension of *Availability of ICT Masterplan* in the sub-module *ICT*, and completed by the dimension of *Environmental* in the *Legal* sub-module.

Concerning TTC's **Priority 1**, in *Level 2*, the KB System has recommended that TTC has to focus on the *Employees* dimension in the *Financial Resource* sub-module. In *Level 3*, the KB System suggested that TTC also needs to focus on the *Soft TQM* sub-module, specifically in the dimension of *Communication*. For *Level 4*, the analysis shows that TTC has to concentrate on the dimension of *Quality Control* within the *Technical* sub-module. With regard to **Priority 2**, the system suggested that for improvement in *Level 2*, TTC should focus on the dimension of

Programmes which belongs to the *Human Resource* sub-module. That should be followed again by the dimension of *LSS Project Manager* (*Share Values* sub-module), and also completed with the dimension of *Operations Budget Compliance* within the *Administrative* sub-module. Finally, for **Priority 3**, TTC has to improve the sub-module *Technology Resource* (*Statistics* dimension), followed by the dimension of *Legacy Systems* in the sub-module *ICT*, and completed as in BEC with the dimension of *Environmental* in the *Legal* sub-module.

Based on the analysis results of the validation process of *Level 5: DMAIC Implementation*, the KB Lean6-SBM model has recommended that for the *Pre-implementation* sub-module priorities, AFHES has to focus first on the *Benchmark* dimension. This has to be followed by the dimensions of *Action, Assessment*, and *Measurement* respectively. With respect to the *Post-implementation* sub-module, the KB System has recommended to start improving the dimension of *Control,* followed by the dimensions of *Measure*, *Analyse*, *Define*, and *Improve* respectively. It is also suggested that AFHES could go into further assessment (*Level 2–Level 4*) due to the high percentage of serious problems (30.9% of the total BPs) that need immediate improvements.

Finally, the chapter demonstrates the KB Lean6-SBM System capability with respect to the *Financial Analysis* sub-module based on industry benchmark. This was successfully proven through assessing a published case study related to one of the leading SBM providers (i.e. **Servest Group Limited)**.

CHAPTER 8

Conclusion and Recommendations

8.1 Introduction

This chapter summarises the thesis findings considering the importance of the designed approach through the implementation of the KB Lean6-SBM System. The development process of KB Lean6-SBM has covered the main strategic and operational issues affecting the Lean6-SBM environment. The developed system serves two types of assessments which are categorised based on whether an organisation attempts to implement LSS for the first time (to evaluate their current readiness), or it needs to evaluate an on-progress/completed LSS project. In both cases, the target is to identify the gap between the existing practice and the industry benchmark of sustainable building maintenance. The developed perspectives for the first type include five Levels: *Level 0: Organisation Environment*, *Level 1: Organisation Business Perspective*, *Level 2: Organisation Resources Perspective*, *Level 3: LSS Readiness for Change*, and *Level 4: LSS Sustainable Building Maintenance Perspective.* The second type of assessment is covered by *Level 5: DMAIC Implementation Perspective*.

8.2 Research Achievements

The aim of this research was to design and develop a hybrid knowledge-based (KB) system for integrated Lean Six Sigma (LSS) linked to the maintenance perspective in a sustainable building context (Lean6-SBM). The system was developed to incorporate GAP analysis and the AHP prioritising technique as a methodology to achieve optimisation and systematic recommendations. The objectives of this research have been successfully achieved in all stages with design, development, implementation, and validation of the KB Lean6-SBM. The gap between the existing condition and the benchmark is thoroughly evaluated before the final recommendation is made. Therefore, the developed KB Lean6-SBM System is capable of assisting the maintenance organisations in their decision-making processes via implementing the Lean6-SBM. The research activities can be summarised as shown in Figure 8.1.

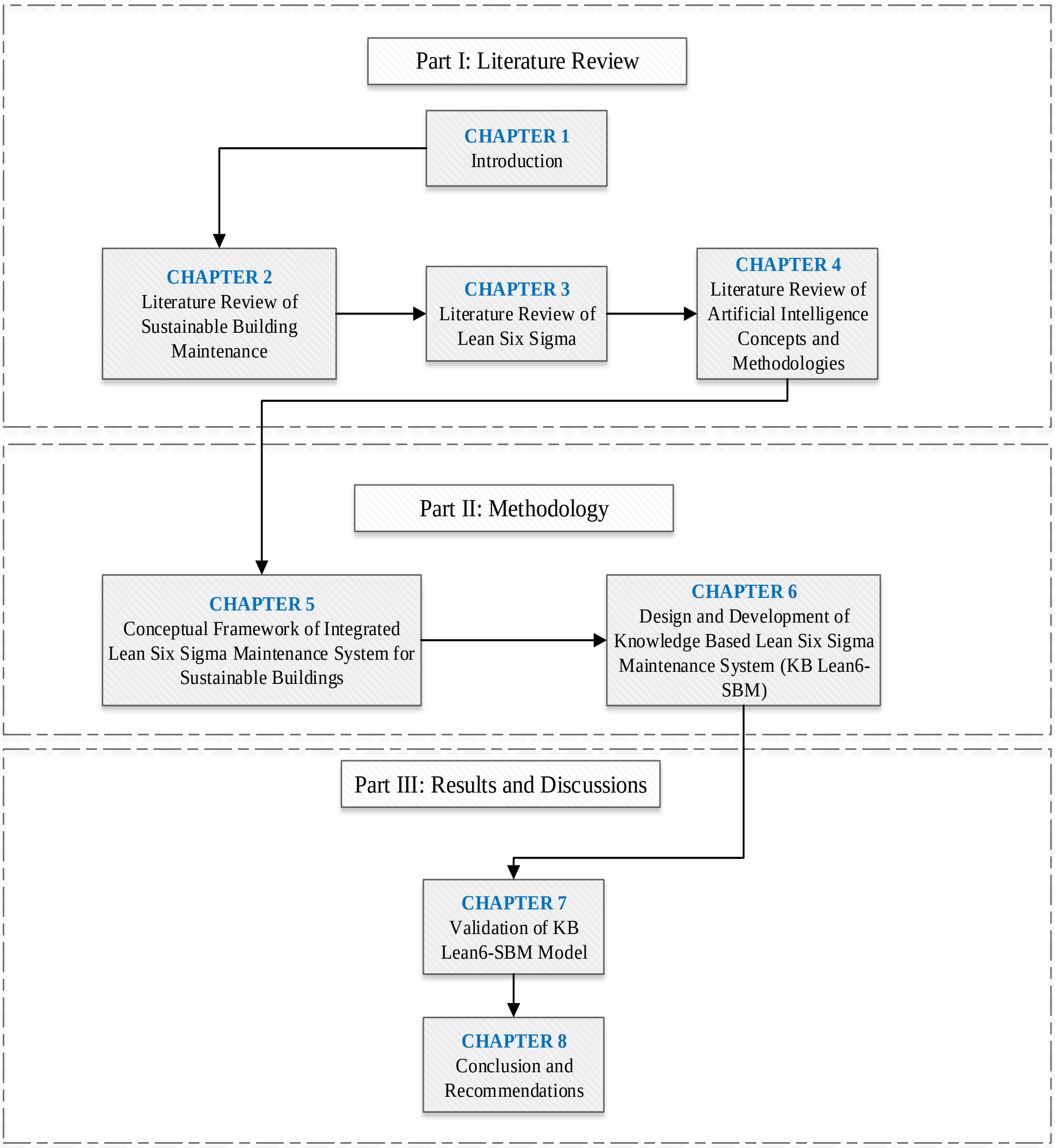


Figure 8. 1 Research Activities' Outline

In this research, Chapters 1, 2, 3, and 4 have proceeded with a background of the problem statement related to the buildings maintenance industry, followed by an extensive literature review in the areas of SBM, LSS, and AI in order to fulfil item *(a)* of the main research objectives.

In Chapter 1, the research has proceeded from a background of the buildings maintenance industry with a special focus on current issues related to the sustainable buildings environment; this was to formulate the research aim and objectives. The chapter has also highlighted the research approach that draws the roadmap of integrating LSS with SBM using a hybrid KB System embedded with GAP and AHP.

Chapter 2 has presented an overview of maintenance strategies in which it was decided that the PM strategy would be the focal point in this research. It was revealed that maintenance performance measurement is categorised into leading and lagging indicators. The chapter also derived the importance of having an SBM strategy and the suitable BM taxonomy that fits such an environment.

Furthermore, Chapter 3 encompasses the review of the evolving LSS philosophy as part of continuous improvement in TQM principles. The chapter has highlighted the main LSS tools and techniques that could add value to the existing practice of maintenance management in an SBM environment; these involve TPM, Kaizen Events, 5S, VSM, SPC, FMEA, and QFD. The chapter has concluded with the need for integrating a readiness-for-change framework within the KB System.

In Chapter 4, the literature review begins by investigating the elements of the DIKW framework. Then, the AI concepts and methodology were reviewed in order to identify the best technique suitable for the design of the hybrid KB Lean6-SBM System. These techniques include CBR, GA, ANN, SA, FBS, Uncertainty, FL, PL, and KBS. Next, an overview of AI to some BM applications was presented. The chapter concluded by reviewing the GAP analysis and AHP technique.

Chapter 5 proposed the KB Lean6-SBM model, which consists of three main stages; these are: Planning (Stage 1), Designing (Stage 2), and Implementation (Stage 3). The model was converted into a conceptual framework and then to a KB System structure that connects six different perspective levels within the SBM organisation; these are: *Organisation Environment*, *Organisation Business Perspectives*, *Organisation Resources Perspective*, *LSS Readiness for Change*, *LSS Sustainable Building Maintenance Perspective,* and *DMAIC Implementation.* The system structure is embedded with GAP and AHP to fulfil the research objectives *(b)* and *(c)*.

Chapter 6 elaborated the detailed development of the KB Lean6-SBM System based on strategic and operational decision levels. In strategic decision levels, the KB System has focused on strategic performance measurement related to *Organisation Environment* (*Level 0*), *Organisation Business Perspectives* (*Level*

1), *Organisation Resources Perspective* (*Level 2*), and *LSS Readiness for Change* (*Level 3*)*. Level 0* is used to capture background and general information about the organisation. In *Level 1*, the system focuses on assessing the financial and market analysis based on the current historical trend. With respect to *Level 2*, the system is designed to evaluate the organisation's resources capabilities to implement LSS from three different perspectives: *Human*, *Technology*, and *Financial*. The last part in the strategic levels is *Level 3*, which is used to determine the organisation's readiness for change. In operational decision levels, the KB System is integrated with two levels: *LSS Sustainable Building Maintenance Perspective* (*Level 4*), and *DMAIC Implementation* (*Level 5*)*.* Level 4 allows the system to assess the organisation's fulfilment to the industry requirement of an SBM environment. Furthermore, Level 5 is designed to serve the DMAIC implementation within the SBM context. This chapter has proved the achievement of the research objective *(d)*.

Chapter 7 discussed the validation process of the KB Lean6-SBM model through real industries and a published case study. This was to ensure the KB System's consistency and reliability that fulfil the research objective *(e)*. There were a total of three (Oman-based) organisations involved in this process: AFHES, BEC, and TTC. Additionally, the data of the published case study was related to the Servest Group Limited Company (UK-based). The validation results and the detailed discussion were presented in this chapter with the emphasis on using GAP and AHP as a powerful combined methodology. The system was found to be consistent and reliable with the capability to identify areas of improvements in a priority manner.

Finally, this chapter concludes the research output, highlighting the advantages and limitations of the research. Based on these, objective *(f)* is also fulfilled by presenting recommendations/suggestions for future research.

8.3 Advantages of the KB Lean6-SBM System

There are several advantages of the KB Lean6-SBM System, which have been identified throughout the design and development process:

- The SBM environment involves the industry benchmark of the triple bottom line of sustainability (i.e. economic, social, and environment), which helps the maintenance organisations to improve their current traditional BM practice with the transformation into a green maintenance approach.

- The KB Lean6-SBM System helps with which LSS tools and techniques to use (based on an extensive literature review) according to various activities within the overall SBM organisation's departments.
- The KB Lean6-SBM System provides a decision support mechanism that determines the serious and non-serious problems which act as obstacles towards implementing LSS projects. The system is able to show how to tackle these problems by prioritising the action plan in the focused area.
- The KB Lean6-SBM System provides a methodology that begins with identifying the gaps between the current practice and the industry benchmark using a GAP analysis technique. These gaps represent opportunities of improvements, which have been taken further, by prioritising them using the AHP technique.
- The development of the KB Lean6-SBM System is in an integrated modular basis. However, there is flexibility as any update of knowledge within any stage can be easily amended.

8.4 Limitations of the Research

Although the developed KB Lean6-SBM model has demonstrated potential in recommending and suggesting improvements for the SBM environment, the system is still at the prototype development stage. Thus, some limitations are still valid as described below:

- The KB Lean6-SBM model is designed and developed for the planned PM strategy. Therefore, the system needs some adjustment to fulfil the industry requirements of the performance measurement indicators for the other types of BM strategies.
- It is difficult to benchmark the performance effectiveness (in terms of functionality and acceptance) of the KB Lean6-SBM System due to unavailability of a system designed to integrate SBM with LSS.
- The development of the KB rules only focuses on the important areas to be improved within the Lean6-SBM context. Nevertheless, there are

unlimited rules that could be implemented in a Lean6-SBM environment, which become impossible to include in such a limited scope.

- The developed KB Lean6-SBM is facilitated by the *AM Builder* software, which has a limitation in term of insufficient memory and hence, affecting the performance of the application.
- This research has used the explanation facility to overcome the uncertainty factor instead of using fuzzy logic or Bayesian logic. Thus, the assumption that the organisation's participant understands the system's questions with related explanations must be taken into account.
- The developed KB Lean6-SBM System is considered similar to other KBS initiatives. According to Mosqueira-Rey et al. (2008), a KBS is considered to be a 'black box' in the validation process, where the user can see only the output as a result of a set of inputs evaluated. This is because the reasoning, and the rules development process, have been carried out by the knowledge engineer with the assistance of human experts in the field of Lean6-SBM. Therefore, the organisation's management level may not appreciate the working effort in developing the KBS as it is difficult to let them visualise the reasoning process inside the system.

8.5 Recommendations for Future Work

There are some recommendations for the KB Lean6-SBM future work improvement as explained in the following points:

- The knowledge acquisition in this research is focused on the area of the planned PM strategy. It is, therefore, recommended to expand to other maintenance areas such as immediate opportunistic maintenance (IOM), and CM strategies, so that the KB Lean6-SBM is a complete system to serve the SBM environment before or after detecting faults.
- The developed KB Lean6-SBM has not considered focusing on supply chain management (SCM) as part of the research scope. As for future work, it is recommended to integrate a separate module that incorporates such a perspective in an SBM environment.
- This research contains over 2500 KB rules forming the KB Lean6-SBM System. Thus, for the above suggested areas of expansion, it is

recommended that another 3000 rules be added to the developed KB System.

- The industrial validation process was performed in an Omani SBM environment, which differs from many other countries in terms of regulations, practice, and culture. Therefore, the KB Lean6-SBM is recommended to be validated in other countries, which have a different culture, and strict policies, and regulations with respect to sustainability.
- The validation process was conducted in a sustainable buildings environment which differs in some aspects from the other type of assets environment. It is therefore recommended to validate the KB Lean6-SBM System in the other maintenance environment (e.g. a power plant) by adjusting the KB rules to suit the new application.
- The development of the KB Lean6-SBM model has considered the assessment of profit margins only at *Level 1* of the strategic decision levels. For a future recommendation, it is suggested that the profit margins are calculated in each module to identify and monitor the financial criticality areas which need more attention. Additionally, this will help the SBM organisation to address the issue of assessing the value of the system in the entire Lean6-SBM environment.

8.6 Final Remarks

This chapter has wrapped up the research outcome by discussing the *Planning*, *Designing*, and *Implementation* stages of the KB Lean6-SBM model. The development process has determined six main perspectives (Levels) to focus on. These Levels incorporate GAP analysis and the AHP technique which are embedded in the system. In addition, this chapter has identified the research achievements based on the main objectives declared in Chapter 1. It has also discussed the advantages of the KB Lean6-SBM System, the research limitations, and the recommendations for future work. It has proved the consistency and reliability of the KB Lean6-SBM System which provides a proper guiding tool for the decision makers in the field of SBM.

The development of the KB Lean6-SBM System was inspired from the extensive literature review in the areas of SBM environment, LSS philosophy, and

AI concepts and methodologies. It was found that SBM organisations require adoption of continuous improvement techniques to become competitive. One of the approaches was to implement an LSS philosophy in such an environment. The complexity of integrating both environments enhances the need for expert knowledge to ensure the system's validity. Amongst the AI techniques, the KBS has been selected to support the platform of the 2500 KB rules created.

The developed KB Lean6-SBM System has scrutinised the entire Lean6-SBM environment from both strategic and operational perspectives. It has covered the organisation's background, business analysis, and resources, including the DMAIC implementation cycle. The system was structured into six modules and 15 sub-modules incorporated with GAP and AHP techniques to form the hybrid KB Lean6-SBM System.

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APPENDIX A

THE AHP CALCULATION PROCEDURE

This example is to illustrate the process of pairwise comparisons based on the KB Lean6-SBM results taken from the Level 3: *LSS Readiness for Change* of TTC (Table A.1) after applying the GAP analysis.

Table A.1 Matrix of AHP Pairwise Comparisons

Aspect	ICT	Share Values	Soft TQM
ICT	1	1/3	1/4
Share Values	3	1	1/3
Soft TQM	4	3	1

The next step is to synthesis the judgments in the matrix. This is done by adding-up the value in each column to get the total value as shown in Table A.2.

Table A.2 Synthesising the Matrix of AHP Pairwise Comparisons

Aspect	ICT	Share Values	Soft TQM
ICT	1	1/3	1/4
Share Values	3	1	1/3
Soft TQM	4	3	1
Σaij =	8	4.33	1.58

Then, the normalisation step is taken place where it divides each entry in a column by the total value of that specific column as shown in Table A.3.

Table A.3 Normalising the Matrix of AHP Pairwise Comparisons

Aspect	ICT	Share Values	Soft TQM
ICT	1/8	0.33/4.33	0.25/1.58
Share Values	3/8	1/4.33	0.33/1.58
Soft TQM	4/8	3/4.33	1/1.58
Σaij =	8	4.33	1.58

The following step is to calculate the Priority Vector (PV) for each aspect. This is done by calculating the average value of the ICT, Share Values, and Soft TQM aspects as demonstrated in Table A.4.

Table A.4 Priority Vectors of the AHP Matrix

Aspect	ICT	Share Values	Soft TQM	Total	Average = PV
ICT	0.13	0.08	0.16	0.37	0.12
Share Values	0.38	0.23	0.21	0.82	0.27
Soft TQM	0.5	0.69	0.63	1.82	0.61

In order to ensure the consistency of the above results to an acceptable level of decision making, the Consistency Ratio (CR) has to be determined. This will consequently affect in the judgment taken by the decision maker. According to Satty (1990), the value of the CR should not exceed 10%, otherwise, there is inconsistency and the judgment has to be reviewed. The mathematical process integrates the weights and creates an evaluation for the decision alternatives. The process begins by calculating the value $\lambda_{\max}$-N which represents the deviation of the judgment from the consistent value (Satty, 1990).

To start, each entry in the AHP matrix is multiplied by the PV value as shown in Table A.5.

Table A.5 Multiplication of Entries with PV

ICT	1 x 0.12	0.33 x 0.27	0.25 x 0.61
Share Values	3 x 0.12	1 x 0.27	0.33 x 0.61
Soft TQM	4 x 0.12	3 x 0.27	1 x 0.61

Then, the values in each raw is added-up to get the total value of the raw that will be used to measure the New Vector (NV). Thus, the NV value is calculated by dividing the total value in each raw by the corresponding PV value as tabulated in Table A.6.

Table A.6 Calculation of NV Values

				Total	NV
ICT	0.12	0.09	0.15	0.36	0.36/0.12 = 3
Share Values	0.36	0.27	0.20	0.83	0.83/0.27 = 3.07
Soft TQM	0.48	0.81	0.61	1.9	1.9/0.61 = 3.11

Therefore, $\lambda_{\max} = \frac{3+3.07+3.11}{3}$ = 3.06

Based on Satty (1990), the CR= CI/RI; where CI is the Consistency Index, and RI is the Random Index.

CI =($\lambda_{\max}$-N)/(N-1); N= matrix size

CI = (3.06-3)/2 = 0.03

Satty (2007) has approximated the RI value for various matrix sizes (N) based on a large simulation runs. These values are presented in Table A.7.

Table A.7 Random Index Value Based on Matrix Size

N	1	2	3	4	5	6	7	8
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.41

Based on the above table, the requested RI for this particular calculation is 0.52, and hence the CR value can be calculated as follows:

CR = CI/RI

= 0.03/0.52

= 0.058 (= 5.8%)

Having the CR value ≤ 10% justifies that the judgment made by the KB Lean6-SBM is consistent and the decision can be taken based on the highest PV.

APPENDIX B

SYSTEM RESULTS OF TECHNICAL TRADING CO. LLC (TTC)

Table B.1 Inputs of Organisation Environment for Organisation TTC

Variables Description	**Data**		
Name of user/interviewee	Mr. Sanath Karunan		
Post	Operation Manager		
Organisation	Technical Trading Co. LLC		
Address of the organisation	Sultanate of Oman, Muscat, Ruwi		
Age of the organisation	46 years		
Last year turnover	£5 million		
Key products/services	HVAC installation & maintenance, Mechanical, electrical, and plumbing (MEP) services, Fire and Safety.		
Key departments	HR & Admin, Finance, MEP, Legal, and Commercial		
Number of employees	>130		
Position in the maintenance strategic system	Maintenance as integrated strategic organisational system		
Key market	Airports, Hospitals, Hotels, Industrial facilities, Sports complexes, Commercial & residential complexes		
Key competitors	ONIEC and BEC		
	Age of Relationship		
	< 5 years	**5 – 10 years**	**> 10 years**
Number of suppliers	No information	No information	No information
Number of customers	No information	No information	No information
Lean6-SBM Capability	**(1-5 Years)**	**(6-10 Years)**	**> 10 years**
Preventive maintenance planning	Capable	Capable	Capable
Preventive maintenance scheduling	Capable	Capable	Capable
Preventive maintenance execution	Capable	Capable	Capable
Preventive maintenance quality control	Capable	Capable	50%
Outsourcing	Nil	Nil	Yes

Table B.2 Output Results of Level 0: *Organisation Environment Perspective* Module

Category	Description
Size of the organisation	Small
Type of organisation in maintenance industry	Open System Organisation
Business cycle stage	Harvest stage
Category of organisation within SMEs	Autonomous
Relationship with Suppliers	No information
Relationship with Customers	No information
Strategic development	Yes
Lean6-SBM activities	• Capable for all activities in last (1-5 years)
	• Capable for all activities in last (6-10 years)
	• Capable for preventive maintenance planning, scheduling, and execution activities in last (>10 years)

Table B.3 The inputs and output results of Market Analysis Sub-module

Inputs				
Competition and Market share				
	2016		**2015**	**2014**
Number of competitors	May-20		May-20	May-20
Market share percentage	10%		10%	10%
Competitors				
Ranking the competitors according to decreasing strength	Organisation		Type of business	
	1	BEC	FM (hard & soft services)	
	2	ONIEC	FM (hard services)	
	3	GENETCO	FM (hard services)	
Output				
The trend of market share and competition is steady for last three years				

Table B.4 GAP analysis results of the *Level 2 - Organization Resources Perspective*

Level 2: Organisation Resources Perspective GAP Analysis: TTC									
Sub-module	Dimensions	No. Questions	Good Point	Bad Point	Problem Category (PC)				
					1	2	3	4	5
Human Resource	Commitment	18	18	0	0	0	0	0	0
	Programmes	30	28	2	1	1	0	0	0
	Statistics	54	44	10	0	0	0	7	3
	Sub-total	**102**	**90**	**12**	**1**	**1**	**0**	**7**	**3**
Technology Resource	Commitment	18	18	0	0	0	0	0	0
	Programmes	44	40	4	0	0	0	4	0
	Statistics	48	42	6	0	0	0	6	6
	Sub-total	**110**	**100**	**10**	**0**	**0**	**0**	**10**	**0**
Financial Resource	Employees	9	2	7	0	1	4	2	0
	Technology	9	5	4	0	0	0	4	0
	Implementation	12	5	7	0	0	0	7	0
	Sub-total	**30**	**12**	**18**	**0**	**1**	**4**	**13**	**0**
Total		**242**	**202**	**40**	**1**	**2**	**4**	**30**	**3**

Tables B.5 *Human Resource* AHP analysis with PV for Organisation TTC

Human Resource	Commitment	Programmes	Statistics	P.V
Commitment	1	1/2	1/2	0.1976
Programmes	2	1	2	**0.4905**
Statistics	2	1/2	1	0.3119

Tables B.6 *Technology Resource* AHP analysis with PV for Organisation TTC

Technology Resource	Commitment	Programmes	Statistics	P.V
Commitment	1	1/2	1/2	0.1975
Programmes	2	1	1/2	0.3119
Statistics	2	2	1	**0.4905**

Tables B.7 *Financial Resource* AHP analysis with PV for Organisation TTC

Financial Resource	Employees	Technology	Implementation	P.V
Employees	1	3	3	**0.5889**
Technology	1/3	1	1/2	0.1593
Implementation	1/3	2	1	0.2518

Tables B.8 Level 2: *Organisation Resources Perspective* AHP analysis with PV for Organisation TTC

Level 2	Human Resource	Technology Resource	Financial Resource	P.V
Human Resource	1	2	1/3	0.2252
Technology Resource	1/2	1	1/3	0.1326
Financial Resource	3	3	1	**0.5889**

Table B.8 Summary of AHP PV values for Level 2: *Organisation Resources Perspective* for Organisation TTC

Level 2: Organisation Resources Perspective			
Sub-module	**Priority Vector**	**Dimension**	**PV**
Human Resource	0.2252	Commitment	0.1976
		Programmes	**0.4905**
		Statistics	0.3119
Technology Resource	0.1326	Commitment	0.1975
		Programmes	0.3119
		Statistics	**0.4905**
Financial Resource	**0.5889**	Employees	**0.5889**
		Technology	0.1593
		Implementation	0.2518

Table B.10 GAP analysis results of Organisation TTC: *Level 3 – LSS Readiness for Change*

Level 3: LSS Readiness for Change GAP Analysis: TTC									
Sub-module	Dimensions	No. Questions	Good Point	Bad Point	Problem Category				
					1	2	3	4	5
ICT	Availability of ICT Masterplan	19	19	0	0	0	0	0	0
	Legacy Systems	33	21	12	0	0	0	12	0
	Sub-total	**52**	**40**	**12**	**0**	**0**	**0**	**12**	**0**
Share Values	LSS Project Manager	12	3	9	0	0	6	3	0
	Cross-functional Collaboration	5	3	2	0	0	0	0	2
	Shared Believes	23	5	18	0	0	0	0	18
	Sub-total	**40**	**11**	**29**	**0**	**0**	**6**	**3**	**20**
Soft TQM	Commitment	24	0	24	0	1	10	8	5
	Communication	20	1	19	4	2	10	3	0
	Culture	14	0	14	1	0	0	11	2
	Sub-total	**58**	**1**	**57**	**5**	**3**	**20**	**22**	**7**
Total		**150**	**52**	**98**	**5**	**3**	**26**	**37**	**27**

Tables B.11 *ICT* AHP analysis with PV for Organisation TTC

ICT	Availability of ICT Masterplan	Legacy Systems	P.V
Availability of ICT Masterplan	1	2	0.3333
Legacy Systems	1/2	1	**0.6667**

Tables B.12 *Share Values* AHP analysis with PV for Organisation TTC

Share Values	LSS Project Manager	Cross-functional Collaboration	Shared Believes	P.V
LSS Project Manager	1	3	2	0.5390
Cross-functional Collaboration	1/3	1	1/2	0.1638
Shared Believes	1/2	2	1	0.2972

Tables B.13 *Soft TQM* AHP analysis with PV for Organisation TTC

Soft TQM	Commitment	Communication	Culture	P.V
Commitment	1	1/3	1/2	0.1759
Communication	3	1	3	**0.6389**
Culture	2	1/3	1	0.2685

Tables B.14 Level 3: *LSS Readiness for Change* AHP analysis with PV for Organisation TTC

Level 3	ICT	Share Values	Soft TQM	P.V
ICT	1	1/3	1/4	0.1199
Share Values	3	1	1/3	0.2721
Soft TQM	4	3	1	**0.6080**

Table B.15 Summary of AHP PV values for Level 3: *LSS Readiness for Change* for Organisation TTC

Level 3: LSS Readiness for Change			
Sub-module	**Priority Vector**	**Dimension**	**PV**
ICT	0.1199	Availability of ICT Masterplan	0.3333
		Legacy Systems	**0.6667**
Share Values	0.2721	LSS Project Manager	**0.5390**
		Cross-functional Collaboration	0.1638
		Shared Believes	0.2972
Soft TQM	**0.6080**	Commitment	0.1759
		Communication	**0.6389**
		Culture	0.2685

Table B.16 GAP analysis results of Organisation TTC: *Level 4 – LSS Sustainable Building Maintenance Perspective*

Level 4: LLS Sustainable Building Maintenance GAP Analysis: TTC										
Sub-module		Dimensions	No. Questions	Good Point	Bad Point	Problem Category				
						1	2	3	4	5
Legal		Contractual attributes	64	63	1	1	0	0	0	0
		Environmental	71	47	24	1	1	0	22	0
		Social	63	56	7	0	2	0	5	0
		Economic	43	41	2	0	0	2	0	0
		Sub-total	**241**	**207**	**34**	**2**	**3**	**2**	**27**	**0**
Technical	Work Orders	Planning	38	36	2	2	0	0	0	0
		Scheduling	23	23	0	0	0	0	0	0
		Execution	25	18	7	1	0	1	3	2
		Quality Control	50	18	32	29	0	2	1	0
		Sub-total	**136**	**95**	**41**	**32**	**0**	**3**	**4**	**2**
Administrative	Budget Comp.	Strategic Budget Compliance	9	9	0	0	0	0	0	0
		Preventive Maintenance Cost Analysis	19	18	1	1	0	0	0	0
		Operations Budget Compliance	3	2	1	1	0	0	0	0
		Sub-total	**31**	**29**	**2**	**2**	**0**	**0**	**0**	**0**
Total			**408**	**331**	**77**	**36**	**3**	**5**	**31**	**2**

Tables B.17 *Legal* AHP analysis with PV for Organisation TTC

Legal	Contractual attributes	Environmental	Social	Economic	P.V
Contractual attributes	1	1/2	1/2	2	0.1981
Environmental	2	1	2	2	**0.3873**
Social	2	1/2	1	2	0.2748
Economic	1/2	1/2	1/2	1	0.1397

Tables B.18 *Technical* AHP analysis with PV for Organisation TTC

Technical	Planning	Scheduling	Execution	Quality Control	P.V
Planning	1	2	1/2	1/7	0.1057
Scheduling	1/2	1	1/2	1/7	0.0730
Execution	2	2	1	1/6	0.1493
Quality Control	7	7	6	1	**0.6721**

Tables B.19 *Administrative* AHP analysis with PV for TTC

Administrative	Strategic Budget Compliance	Preventive Maintenance Cost Analysis	Operations Budget Compliance	P.V
Strategic Budget Compliance	1	1/2	1/5	0.1179
Preventive Maintenance Cost Analysis	2	1	1/4	0.2014
Operations Budget Compliance	3	4	1	**0.6807**

Tables B.20 Level 4: *LSS Sustainable Building Maintenance Perspective* AHP analysis with PV for Organisation TTC

Level 4	Legal	Technical	Administrative	P.V
Legal	1	1/4	1/2	0.1373
Technical	4	1	3	**0.6232**
Administrative	2	1/3	1	0.2395

Table B.21 Summary of AHP PV values for Level 4: *LSS Sustainable Building Maintenance Perspective* for Organisation TTC

Level 4: LLS Sustainable Building Maintenance			
Sub-module	**Priority Vector**	**Dimension**	**PV**
Legal	0.1373	Contractual attributes	0.1981
		Environmental	**0.3873**
		Social	0.2748
		Economic	0.1397
Technical	**0.6232**	Planning	0.1057
		Scheduling	0.0730
		Execution	0.1493
		Quality Control	**0.6721**
Administrative	0.2395	Strategic Budget Compliance	0.1179
		Preventive Maintenance Cost Analysis	0.2014
		Operations Budget Compliance	**0.6807**