

Product Based Information Sharing in Project Management

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The thesis is submitted in partial fulfilment of the requirements for the award of the degree of
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Declaration

Whilst registered as a candidate for the above degree, I have not been registered for any other research award. The results and conclusions embodied in this thesis are the work of the named candidate and have not been submitted for any other academic award.

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Abstract

Planning a project with proper considerations of all necessary factors and managing a project to ensure its successful implementation are facing a lot challenges. Initial stage in planning a project is costly, time consuming and usually with poor accuracy on cost and effort predictions. On the other hand, detailed information for previous projects may be buried in piles of archived documents, which make it increasingly difficult to learn from the previous experiences. Current information sharing methods to support project management focus on activity based project operation and processes but lack some granulations on project deliverables, especially when project context and customer requirements are varied. This research develops a product based information sharing (PBIS) framework, which attempts to serve in general project planning and lead to properly and effectively benchmarking and recommending product portfolios for project management purposes.

PBIS made contributions in various areas. It introduced a new product based approach to capture and reuse the project information that tackles the issue of information sharing from a very different perspective. The Project Analyser part articulates requirement information at both project and product levels. The analysed results can be used to assist the product based breakdown process which is validated by product refinement rules. The Project Planner part enables project plan to be generated accurately and efficiently through a novel product benchmarking and recommendation mechanism. This mechanism integrated with the strengths of Quartile, Data Envelopment Analysis (DEA) and Analytic Hierarchy Process (AHP) to ensure the right products are selected based on products of which attributes are important for customer criteria during the project planning stage. A novel software system iPAS based on PBIS has been developed to bridge the gap between PBIS main principles and its application, with providing the user with automated planning, monitoring, reports and human resource allocation.

PBIS has been trialled with cases studies in two organisations, which clearly shows the business benefits of autonomic project management. It reduced effort to plan new projects and manage project portfolio and decreased estimation bias thereby reducing operational risk. It also automatically benchmarked performance against company best practices. As a result, the PBIS can be used to solve other real world problems in standardised industries such as manufacture, education, medicine, construction and rail industries etc.

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Table of Content

Declaration	2
Abstract	3
Acknowledgements	4
Table of Content.....	5
List of Figures	8
List of Tables.....	10
Disseminations	12
Abbreviations	13
Chaper 1. Introduction.....	14
1.1 Motivation.....	15
1.2 Research Aims	18
1.3 Major Contributions.....	19
1.4 Thesis Organisation.....	20
Chapter 2. Background and Related Work.....	22
2.1 Project Management	22
2.1.1 Project Definition and Objectives.....	22
2.1.2 Project Management and Methodologies.....	23
2.2. Project Planning	30
2.2.1 Activity Based Planning (ABP).....	31
2.2.2 Limitations of ABP.....	32
2.2.3 Product Based Planning (PBP)	33
2.2.4 Advantages of PBP.....	34
2.2.5 Challenges of PBP	37
2.3 Project Information Sharing	38
2.3.1 Knowledge and Information	39
2.3.2 Knowledge Management.....	40
2.3.3 Shared Information in Project Management.....	41
2.3.4 Challenges of Project Information Sharing.....	42
2.3.5 Project Portfolio Management (PPM)	43
2.4 Benchmarking for Information Sharing	46
2.4.1 Best Practice Benchmarking.....	46
2.4.2 Benchmarking Criteria Selection.....	47
2.4.3 Benchmarking Approaches.....	48

2.4.3.1 Ratio-based Metrics Approach	48
2.4.3.2 Cost-based Metrics Approach	48
2.4.3.3 Quartile Approach	49
2.4.3.4 Data envelopment analysis (DEA)	49
2.4.3.5 Analysis Hierarchy Process (AHP)	50
2.4.3.6 Hybrid Method - AHP and DEA	52
2.5 Summary	53
Chapter 3. Product Based Information Sharing (PBIS) Framework	54
3.1 Overview of PBIS Framework	54
3.2 Project Analyser	57
3.2.1 Requirements Articulation	57
3.2.1 Product Breakdown	58
3.2.3 Rules for Product Refinement and Breakdown	64
3.3 Project Planner	66
3.3.1 Product Based Project Portfolio Repository	66
3.3.2 Product Benchmarking and Recommendation Engine	68
3.3.3 Plan Generator	70
3.6 Summary	70
Chapter 4. Product Benchmarking and Recommendation Mechanism	73
4.1 Overview	74
4.2 Criteria Generator	77
4.3 Product Benchmarking	78
4.4 Products Further Selection	83
4.5 AHP Based Product Recommendation	87
4.5.1 Construction of Criteria Hierarchy for the Decision Making	87
4.5.2 Pairwise Comparison of the Criteria and Sub Criteria	89
4.5.2.1 Criteria Pairwise Comparison	90
4.5.2.2 Sub Criteria Pairwise Comparison	93
4.5.3 Criteria Weight Aggregation and Priority Calculation	95
4.6 Summary	97
Chapter 5. Intelligent Project Automation Systems - iPAS	99
5.1 Motivation of iPAS Tool	99
5.2 Overview of iPAS Functions	100
5.2.1 Project Planning	100
5.2.2 Human Resource Management and Profiling	105
5.2.3 Project Monitoring and Alert Mechanism	106
5.2.4 Project Reporting	108

5.3 Summary	110
Chapter 6. Case Studies and Evaluation Results	111
6.1 Case Study One	111
6.1.1 Background.....	111
6.1.2 Application of PBIS Framework	113
6.1.2.1 Product Based Breakdown	114
6.1.2.2 Project Planning and Monitoring.....	118
6.2 Case Study Two	127
6.3 Evaluations and Results	129
6.3.1 Evaluation through Case Studies	129
6.3.1.1 Evaluation Results for Company A Projects	129
6.3.1.2 Evaluation Results for NPL Projects.....	134
6.3.2 Evaluation through Questionnaire	137
6.3.3 Evaluation through Session Meetings and Workshops.....	142
6.3.4 Compare iPAS with Other Project Management Tools	144
6.3.5 Justification for Data Analysis Techniques	147
6.4 Critical Review	148
6.5 Summary	149
Chapter 7. Conclusion and Future Work.....	150
7.1 Concluding Remarks.....	150
7.2 Future Work	153
7.2.1 Construct A Method to Articulate Product Selection Criteria for Benchmarking	153
7.2.2 Extension of iPAS Tool	155
References	157
Appendix A – Calculations from Considering P2, P3, P4 and P5 as Focal DMUs.....	179
Appendix B – Evaluation Questionnaire	182
Appendix C - FORM UPR16	184
Appendix D - Certificate of Ethics Review.....	185

List of Figures

Figure 2-1: Time, Cost, and Quality Triangle (Constable, 1995).....	23
Figure 2-2: The Overall Architecture of the RUP Method (IBM, 2006).....	25
Figure 2-3: The Agile Process Model (Rana, 2009).....	26
Figure 2-4: The PMBOK Process Model (PMBOK® Guide, 2017).....	27
Figure 3-1: Product Based Information Sharing (PBIS) Framework	55
Figure 3-2: A Product Breakdown Structure.....	61
Figure 3-3: A Project Flow Diagram.....	63
Figure 4-1: Product Benchmarking and Recommendation Mechanism.....	75
Figure 4-2: Quartile Points	78
Figure 4-3: The AHP hierarchy	88
Figure 4-4: Four level hierarchy model for selection of best product	88
Figure 5-1: Create A New Project Page	101
Figure 5-2: Configure Project Products.....	103
Figure 5-3: A Project Gantt Plan	104
Figure 5-4: A Product with Associated Activities.....	104
Figure 5-5: Human Resource Management Page.....	106
Figure 5-6: The Project Tolerance Grid	107
Figure 5-7: Project Report.....	109
Figure 6-1: SOW Exmample for PSE Project – Deliverable Specification.....	115
Figure 6-2: SOW Exmample for PSE Project – System Requirements	116
Figure 6-3: PSE Project - Product Break Structure	117
Figure 6-4: PSE Project - Product Flow Diagram	118
Figure 6-5: Create A New Project Page	119
Figure 6-6: Setup Project Performance Criteria	119
Figure 6-7: Project Portfolio Selection Page	122
Figure 6-8: Project Plan with Gantt Chart.....	123
Figure 6-9: Product Detail Page	124
Figure 6-10: Activity Detail Page.....	125
Figure 6-11: Project Monthly Report	125
Figure 6-12: Product Report.....	126
Figure 6-13: Return on Investment (ROI) Comparisons	131
Figure 6-14: Cost Performance Index (CPI) Comparisons	132
Figure 6-15: Schedule Performance Index (SPI) Comparisons.....	132
Figure 6-16: Planning Performance Index (PPI) Comparisons	133

Figure 6-17: Comparisons of Spent Time on Each Project Planning Stage	133
Figure 6-18: Return on Investment (ROI) Comparisons – NPL projects.....	135
Figure 6-19: Cost Performance Index (CPI) Comparisons – NPL projects	135
Figure 6-20: Schedule Performance Index (SPI) Comparisons – NPL projects	136
Figure 6-21: Planning Performance Index (PPI) Comparisons – NPL projects.....	136
Figure 6-22: Comparisons of Spent Time on Each Project Planning Stage – NPL projects.	137
Figure 6-23: Question 1.....	138
Figure 6-24: Question 2.....	139
Figure 6-25: Question 3.....	139
Figure 6-26: Question 4.....	140
Figure 6-27: Question 5.....	140
Figure 6-28: Question 6.....	141
Figure 6-29: Question 7.....	141

List of Tables

Table 3-1: Product Description of Service Level Agreement	62
Table 3-2: Product Based Portfolios.....	67
Table 4-1: Performance benchmarking criteria for product selection	77
Table 4-2: Quartile Levels.....	79
Table 4-3: Example of Historic Data in Time Order.....	81
Table 4-4: Example of Historic Data in Cost Order	82
Table 4-5: The raw data of the benchmarked products	84
Table 4-6: The pre-selection results based on the equal weights	85
Table 4-7: The results from considering P1 as a focal DMU	85
Table 4-8: The consolidated DEA results for the DMUs	86
Table 4-9: Saaty’s pair-wise comparison nine-point scale for AHP preference (2012).....	89
Table 4-10: Matrix containing weights	89
Table 4-11: <i>RI</i> with $n=10$ pair-wise comparison matrix.....	90
Table 4-12: Pairwise comparison matrix with intensity judgments	91
Table 4-13: Normalized matrix	91
Table 4-14: Level 1 pair-wise comparison results.....	91
Table 4-15: Priorities as factors.....	92
Table 4-16: Calculation of weighted columns and weighted sum.....	92
Table 4-17: Calculation of average of the values	92
Table 4-18: <i>RI</i> with $n=3$ pair-wise comparison matrix.....	93
Table 4-19: Pairwise comparison matrix with intensity judgments	93
Table 4-20: Normalized matrix	93
Table 4-21: Level 2 pair-wise comparison results.....	94
Table 4-22: Priorities as factors.....	94
Table 4-23: Calculation of weighted columns and weighted sum.....	94
Table 4-24: Calculation of average of the values	94
Table 4-25: Pairwise comparison matrix with intensity judgments	95
Table 4-26: Level 2 pair-wise comparison results.....	95
Table 4-27: Derived priorities for the sub criteria against each of the products	95
Table 4-28: Global priorities for the recommended product decision.....	96
Table 6-1: Example of Product Portfolio	120
Table 6-2: Comparison Results of Completed Projects in Company A	130
Table 6-3: Comparison Results of Completed Projects in NPL.....	134
Table 6-4: Culture Changes before and After Using PBIS	144

Table 6-5: Project Management Tools Comparison List.....	145
Table A-1: The results from considering P2 as a focal DMU	179
Table A-2: The results from considering P3 as a focal DMU	180
Table A-3: The results from considering P4 as a focal DMU	180
Table A-4: The results from considering P5 as a focal DMU	181

Disseminations

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Abbreviations

ABP.....	Activity Based Planning
AHP.....	Analytic Hierarchy Process
CDRL.....	Contract Data Requirements List
CPI.....	Cost Performance Index
CPA.....	Critical Path Analysis
DEA.....	Data Envelopment Analysis
DMU.....	Decision Making Unit
EV.....	Earned Value
iPAS.....	intelligent Project Management and Automation Systems
ITT.....	Invitation To Tender
LP.....	Linear Programming
MOD.....	Ministry of Defence
NAM.....	Norm Analysis Method
NPL.....	National Physical Laboratory
PBIS.....	Product Based Information Sharing
PBP.....	Product Based Planning
PBPP.....	Product Based Project Portfolio
PBS.....	Product Breakdown Structure
PD.....	Product Descriptions
PERT.....	Program Evaluation and Review Technique
PFD.....	Product Flow Diagram
PMBOK.....	Project Management Body of Knowledge
PPI.....	Planning Performance Index
PPM.....	Project portfolio management
PRINCE.....	Projects IN Controlled Environments
ROI.....	Return on Investment
RUP.....	Rational United Process
SAM.....	Semantic Analysis Method
SPI.....	Schedule Performance Index
SOW.....	Statement of Work
WBS.....	Work Breakdown Structure
WLC.....	Whole Life Cost

Chaper 1. Introduction

Effective management of projects is becoming increasingly important for organisation to remain competitive in today's dynamic business environment due to pressure of globalisation. Both managers and management theorists are increasingly challenged of managing knowledge that ensure project success, and reusing previous solutions to meet project's quality specifications on cost, schedule, and performance. In order to manage and learn the knowledge, project team members in organisation must create, share, and apply knowledge (Almahamid and Lee, 2010; Ketvirtis 2016). As each project has different plans, results, problems, and successes that offer an opportunity to learn from, by integrating and sharing these experiences and learning across projects, the organisations need a proper method to capture and then use them for future business activities. Current knowledge sharing methods to support project management focus on activity based project operation and processes but lack some granulations on project deliverables, especially when project context and customer requirements are varied.

On the other hand, detailed information for previous projects may be buried in piles of archived documents, which make it increasingly difficult for project organisation to learn from the previous experiences. Although project portfolio and best practise benchmarking have been brought into this field aiming to improve the information sharing and management among different projects, the amount of information that could be shared is still limited to generic information. The semantics of vast amount of information in between which contains the best practices of producing certain products (deliverables) are not even collected due to the nature of the traditional activity based project planning approach. The issue of how better to share project information and resources from past projects leveraged and re-used as best practices across teams rather a reinvent the wheel, therefore becomes of central concern of the project managers.

This thesis addressed this issue and proposed a product based information sharing (PBIS) framework, which aimed to bring a clear structure into project planning, in order to combat the problems currently being experienced by project managers and tender estimators. The proposed framework incorporates sets of techniques as a new mechanism to ensure the right products to be selected based on customer criteria during the project planning stage. It introduced a product based approach to capture and reuse the project information that tackles the issue of information overloading from a very different perspective. It also overcomes the

limitation of traditional activity based methods when sharing information only at the activity level, and allows maximum information and best practice sharing among projects at the product level. Within the framework, the Project Analyser part articulates requirement information at both project and product levels. The analysed results can be used to assist the product based breakdown process which is validated by product refinement rules. The Project Planner part enables project plan to be generated accurately and efficiently through a novel product benchmarking and recommendation mechanism. With the aim of improving management life and becoming planning automated, an intelligent project automation system (iPAS) has been developed to achieve the goals of the PBIS framework, such as automatically deliver project plans and intelligently assist the management of the Whole Life Cost (WLC) of projects based on the best practices from previous projects. The PBIS framework has been trailed and validated by case studies in manufacturing industry domain and scientific research domain.

1.1 Motivation

In today's business environment, competition amongst companies in the same business domain has become more and more keen. In order to strive for a greater share of the market to sell or buy goods and services, many organisations must win some profitable project contracts. Project contract bidding plays an important role during the conceptual phase of the project life cycle (Kerzner, 2009) as it will provide decision support of whether to bid and how much profit can be made. The bidding proposal must be built around a sound, well-thought-out estimated project plan which addresses the cost, time spent and quality to generate the final product. The estimated project plan should be responsive to clients' delivery requirements, and reflect the objective of manufacturing a product of the desired quality and reliability.

For many years, engineering companies have spent a great deal of time bidding for WLC projects from clients (Neale *et al.*, 2006). Each project plan and associated costing are developed almost from scratch, even when elements of projects are similar to those bid for in the past. This takes considerable time and therefore incurs resource costs which could be a big cost saving. It also means that bids are not always consistent and sometimes contain inaccuracies which can be costly if the project contract is won and the cost profile is proved to be wrong. An overriding problem caused by bidding was the wasted time and effort on projects that were never going to be built or that would be built, but completed at prices far from the estimated contract price (Dixon, 2005). The gap between the theoretical price quote

and the actual completion cost often varied dramatically. The final evaluation from the client often was that somehow “the engineer did a good job but never knew what things were really going to cost” (Emrouznejad *et al.*, 2008). And the incomplete plans and specifications will always end up generating cost-plus contracts, which require considerable administration time and results in disputes over costs, prices and waste. Also upon awarding a contract it is difficult to substantiate existing data on project success to improve customer confidence.

In addition, many engineering products, material and subcontract costs can be as much as 70% of product cost (Crowson, 2005). This means that these costs must be examined very carefully at the time the manufacturing cost estimate is prepared. For best results, direct quotes should be obtained from suppliers or subcontractors. In practice, however, time constraints in completing the project bidding estimate or planning may not allow sufficient time to solicit these quotes, forcing the use of historical cost data for the same or similar parts and materials, factored for inflation and anticipated cost growth (Abhijat, 2009).

Frequently the best practice of assessing through life support resources in the engineering services sector is to benchmark against a similar and previous project by using historical data. Best practice is defined as the most efficient (least amount of effort) and effective (best results) way of accomplishing a task or a deliverable, based on repeatable procedures that have proven themselves over time for large numbers of people (Druery *et al.*, 2013). Benchmarking is considered as a technique to provide a systematic approach to improving business production efficiency and profitability through comparing and analysing the values from varying resources. Thus, benchmarking and utilising best project practice are the key issues for enterprises to persist in contract competition and project planning.

Currently, most project best practices are made explicit in terms of persistent data from operational processes or activities, but underlying influencing factors remains implicit. The risk of such practice is the cost estimation will not take account of other factors such as different environment, technology advances and different customer profiles. Many engineering companies have previously been financially penalised (Neale *et al.*, 2006) by such poor benchmarking techniques. On the other hand, although the detailed information gathered from previous projects will be critical for characterising and planning the “to-be” process of project, that information may be buried in piles of archived documents which can be increasingly difficult to shift and utilise productively. Project and product portfolio has been brought into this field aiming to improve the information sharing and management among different projects. However, the amount of information that could be shared is still limited to generic information. The semantics of vast amount of information in between

which contains the best practices of producing certain products (deliverables) are not even collected (Tang, 2008).

Above issues have been addressed in the research (Williams, 2007, Scales 2010) to capture shareable information between projects by collecting post project reviews that are universal and be useful in any project context. Their method is reflective in the tools and methodologies used, particularly information communication technology systems built for this purpose. However, evidence is accumulating that this approach is not very helpful (Newell *et al*, 2013). As all projects will involve some elements that cannot be directly translated from one to another, also there is also no secure metric system can be used between projects (Maylor, 2003).

Therefore, there is an emerging requirement for a new methodology to help the project manager to generate a project plan which aims to give an estimation of resource costs based on customer requirements and business context through analysing, sharing and reusing data collected from previous completed projects. The new methodology also should be able to provide a future protection mechanism against practice risks.

Research has showed that sharing best practice information from past projects with future projects enhances organizational and project processes (Reich and Gemino, 2008, Reich *et al.*, 2012), therefore there is no doubt that sharing project historical information amongst projects especially can improve project competencies and stimulate project maturity (Barclays and Osei- Bryson, 2010). However, empirical research by Von Zestwitz (2002) and Newell *et al.*, (2006) have shown that projects are still recoding high project failure rates despite adopting information sharing practices. Atkinson *et al.*, (2006) noted that useful project information are rarely captured, retained or indexed, even in cases where the project information is available. Projects are still consistently failing to learn from past projects, repeating the same mistakes and reinventing the wheel (Swan *et al.*, 2010).

What have caused the failure of the application of information sharing in project environments?

Firstly, current information sharing in project management experiences a main problem with using benchmarking of project practices between different projects is that projects by their very nature are unique (Barber, 2004). Activity based approach is the traditional planning approach which has been widely used in many industries for a long time. This benchmarking approach has some limitations. First of all, different people may take different activities to

deliver the same product. They will plan and take preferred activities for the same product based on their own experience and preference. Consequently the experience and information is not easily sharable due to the fact that new technologies, process re-engineering and different personnel preferences may all affect the practices of conducting project activities, unless exactly the new project having exactly the same processes has been planned for. Hence, benchmarking technique may not be utilised properly for project planning and processes controlling if there is not a comparable situation.

Secondly, benchmarking usually focuses on measurable results, but the performance such as the quality of the criteria are not easy to measure quantitatively (Pope *et al.*, 2002). Therefore, how to incorporate benchmarking technologies for sharing information and how to employ appropriate measurements for performance improvements in project management are big challenges.

Based on these compelling challenges, the following research questions emerged:

- What kind of best practise information can be shared between projects to improve future project performance?
- How project best practise information to be captured?
- What is the most effective way to present project best practise information for sharing with other projects?
- How to benchmark project best practise information?

Answering above questions through a theoretical understanding of issues surrounding the area is not only of great value and impact (Reich *et al.*, 2012) to project management researchers, it is also important to practitioners in learning how to share useful best practice information learnt from a executing projects with other projects to improve project performance.

1.2 Research Aims

To answer the above research questions, this thesis aims to create a Product Based Information Sharing (PBIS) framework to serve in general project planning and lead to properly and effectively product benchmarking and recommendation for project management purposes. This framework incorporates sets of techniques such as product based planning, project portfolios management, best practice benchmarking and product recommendation. In addition, the PBIS framework introduces a new product based approach to assist project

manager to capture project plans, results, problems and successes that offer an opportunity to learn from historical projects. A product based portfolio management is also proposed in this thesis to contain detailed information of each project products apart from time, cost, resource and dependencies, such as quality criteria, constrains, experiences and learning across projects and activities underneath. This detailed information is very useful when benchmarking and recommending same or similar historical products for planning a new project or generating relevant business intelligence.

As a promise of improving information sharing, a best practices benchmarking and product recommendation mechanism is utilised in PBIS to deliver reliable results that can help to support decision making and enhance performance of project planning and monitoring. This mechanism integrated with the strengths of Quartile, Data Envelopment Analysis (DEA) and Analytic Hierarchy Process (AHP) to ensure the right products are selected based on products of which attributes are important for customer criteria during the project planning stage.

1.3 Major Contributions

The major contributions of this thesis are as follows:

Product Based Information Sharing (PBIS) framework

This work develops PBIS framework that provides a guide to benchmark and recommend product portfolios for project planning and management. This method integrates with the strengths of several different techniques such as product based planning, project portfolios management, best practice benchmarking and product recommendation, and demonstrates how they can be adapted together in a novel way to solve the research problem. PBIS framework is the new attempt to automate project planning processes with an information system based on previous project delivery and best practices. It also brings the possibility of providing global access for any projects to share product portfolio.

Product benchmarking and recommendation mechanism

The mechanism integrated with the strengths of Quartile, Data Envelopment Analysis (DEA) and Analytic Hierarchy Process (AHP) to ensure the right products are selected based on products of which attributes are important for customer criteria during the project planning stage. This mechanism evaluates an optimisation of the alternative products and determines a ranking for them via qualitative outputs. Compared to the traditional, mainly activity based approach which only quantitative variables are considered, the utilization of this novel

mechanism enables the inclusion of both quantitative and qualitative factors extracted from product based portfolios in the decision process. This is very useful for the projects where some of their performance measures are qualitative in standardised industry.

Implementation and case study

A software tool intelligent Project Management and Automation Systems (iPAS) has been implemented to achieve the goals of the PBIS framework. The system takes advantage of the fact by gathering statistics and best practices from other projects, which provides intelligent assistance during the whole life cycle of projects. It is able to automatically deliver project plans to match customer requirements as well as provides a mechanism for continuous monitoring of project execution.

The practicality of the PBIS framework and iPAS tool has been examined by the use of the case study method and validated feedback received from project experts in manufacturing industry domain and scientific research domain, which clearly shows the business benefits of autonomic project management. It reduces effort to plan new projects and manage project portfolio and decreased estimation bias thereby reducing operational risk. It also automatically benchmarks performance against company best practices. It also effectively allows the system to be applied for other standardised industries. The proposed framework can be of practical use to project based organisations to improve project management by effectively capturing and sharing useful information between projects. In addition, as a daily basis tool, iPAS is specifically designed for managing projects by following a well-defined principle. As a result, the PBIS framework illustrated in this thesis can be used to solve other real world problems in standardised industries such as manufacture, education, medicine, construction and rail industries etc.

1.4 Thesis Organisation

The organisation of this thesis is as follows.

Chapter 1 briefly introduces the research area and motivation, identifies the research problem. Research questions, aim and objectives and assessment of the research contributions are presented as well.

Chapter 2 presents a comprehensive review of the on the current literature on related concepts that supporting the research topics. It offers the motivation or rationale behind various design decisions. And then extends it into the state of arts of algorithms and techniques for current approaches adopted to project information sharing through benchmarking, finally the challenges facing the current practices are highlighted.

Chapter 3 introduces the proposed information sharing framework - Product Based Information Sharing (PBIS) and elaborates each component within this framework in great detail.

Chapter 4 presents the product benchmarking and recommendation mechanism in detail as a part of PBIS framework.

Chapter 5 introduces the intelligent Project Automated Systems (iPAS) based on PBIS framework and its main features that are able to effectively support project management.

Chapter 6 discusses and evaluates the experimental results of applying the PBIS framework in case studies.

Chapter 7 summarizes the thesis and describes the future work.

Chapter 2. Background and Related Work

This chapter reviews the underlying theories, practices and current research work related to project management through information sharing in project based organisations. Section 2.1 overviews the background on project management, with emphasis on the aspects where our proposed method differs from conventional methods. Section 2.2 presents the main project planning approaches, as well as why and under which conditions the existing solutions do not adequately address the issue of information sharing. Section 2.3 provides an overview of the theories and discusses part of the theories that relate with project information sharing. Also the concept of project portfolio management and challenges of project information sharing will be discussed. Finally, section 2.4 introduces benchmarking for project best practice and examines specific benchmarking challenges and some existing approaches.

2.1 Project Management

In a project organization, the management of the times, resource allocations and costs of the projects is a complex process. To complete projects successfully, project managers must apply their knowledge and skills to the project activities and utilise suitable tools in order to complete the project to meet the stakeholders' needs and expectations. Ideally, project managers can utilise the stored project information and their knowledge to serve the future projects in order to learn the lessons and save the management effort, while the detailed information and personal knowledge from previous projects may be buried in piles of archived documents or lost during the changes of project team, which make it increasingly difficult for project organisation to learn from the previous experiences. Therefore, how to capture and transfer the knowledge of project management in order to reuse and survive a compete in the future faces a big challenge. Following section will introduce the theoretical project knowledge and practically proven methods for project management.

2.1.1 Project Definition and Objectives

To understand project management, what is a project must to be recognised. A Guide to the Project Management Body of Knowledge (PMBOK, 2017) defines a project as an endeavour that has a definition objective, consumes resources, and operates under time, cost and quality constraints. Almost all organisations want their projects to be on time, meet quality objectives, and not cost more than the allocated budget. These project attributes are shown in **Figure 2-1**

(Constable, 1995). The triangle demonstrates the three variable parts of a project (time, cost and quality) and gives a simplistic idea as to what happens if one or two of the variable is low. For example, the less time and money available, the more likely the project is to be of low quality. On the other hand, a project budget that has more resources to allocate may be seen to perform better, producing higher quality requirements and fulfilling more stakeholders' needs.

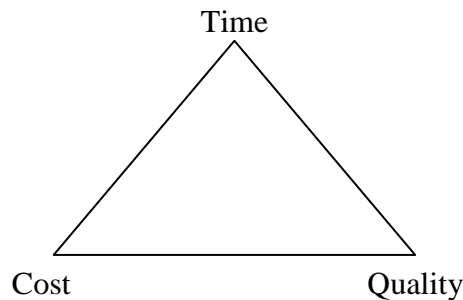


Figure 2-1: Time, Cost, and Quality Triangle (Constable, 1995)

There are a number of benefits associated with successful project management. Decision making routes are clearly defined with deadlines, costs and resources being monitored and controlled systematically. If the project processes run smoothly and remain in harmony with each other, the advantages can include greater flexibility in the project and improved quality of the deliverables. It should be easy to measure project goals throughout the entire project lifecycle in an effective and efficient way, thus being alerted at once too many problems that may arise. Without employing various project management techniques, it is virtually impossible to judge whether a project will be completed in time and within the set budget, and if no requirements are specified, it is difficult to understand how progress has been made from one day to next.

2.1.2 Project Management and Methodologies

There are different variations as to the definition of project management. Olonoff (2000) views project management as an operation of planning and allocating resources, as well as being focused on lessons learned as information and knowledge sharing; when in fact there are learned lessons can be too little to late in the project life cycle to affect positively the project outcome. Project management, also is described as the application of knowledge, skills, tools and techniques to project activities to meet project requirement (PMI, 2006) or the coordination of human, financial and material resources to achieve beneficial change defined by quantitative and qualitative objectives (Turner, 2008).

Other definitions place slightly different emphasis on the definition of project but the concept remains predominantly the same. Reich (2005) provides an inclusive definition of project and project management. In her view, projects are temporary organizations used to deliver value within a specified context, budget and timeline and involve substantial knowledge processing. The success of projects depends on the right combination and application of creative knowledge experience and techniques, thus the dissemination and usage of knowledge is vital for effective project management. This definition introduces knowledge processing to project management definition and this plays a role in this thesis.

In order to manage the complex processes such as time, costs, quality and resource allocation of the project and delivery the high product value with customer expectations, a proper guideline is needed for project practitioners. Project management methodologies are such guidelines that contain guiding processes for those who are doing project management. There are different project management methodologies available, next the most popular project management methodologies will be presented and the challenges they faced on project knowledge transfer and sharing will be discussed.

The Rational United Process (RUP)

The Rational United Process (RUP) has emerged as a popular project management method (Ashraf, 2014), a framework for software development that has been adopted by many businesses that were looking for a well-defined and well documented software development process (Kruchten, 2000; Mohda *et al.*, 2016).

Figure 2-2 illustrates the overall architecture of the RUP method, which has two dimensions: the horizontal axis of RUP architecture diagram represents time, illustrating the various processes that take place within each iteration, which can be viewed in terms of phases or milestones. The vertical axis represents all the necessary group activities, which are divided into workflows, activities, roles and disciplines (IBM, 2006). One of the main cornerstones and most important features of an RUP project is the assignment of roles. Each process in the main RUP lifecycle diagram defines the activities and responsibilities of each role, with the development case providing a list of project artefacts that are mapped onto a specific role along with various activities. This is important as it clarifies the tasks that each project member will be undertaking in each phase and in many projects (Stoen, 2004).

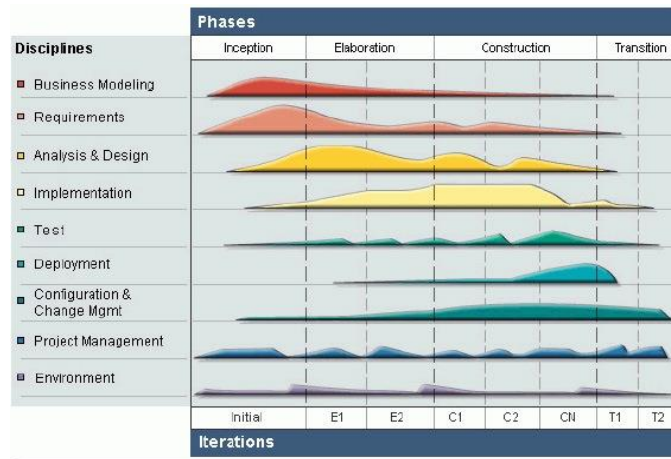


Figure 2-2: The Overall Architecture of the RUP Method (IBM, 2006)

However, the RUP has an extensive project management framework, with many different processes defined and tasks highlighted. In order for a project using the RUP to be successfully completed, the project manager must not only have a clear understanding of how RUP is employed, but must also understand how each process fits into the overall RUP architecture. Therefore, the same RUP processes may not be used in the same organisation for a different project and this could be confusing for anyone who does not have much RUP experience.

Agile Method

Agile methodology is an approach to project management, typically used in software development (Andrew and Nachiappan, 2018). It helps teams respond to the unpredictability of building software through incremental, iterative work cadences, known as sprints. The development follows an iterative and incremental over the sprints since new features are added to the product as shown in **Figure 2-3**. Agile is families of methodologies, not a single approach, some of the well-known Agile methodologies are Extreme Programming (“XP”), Agile Unified Process and Scrum (Andrew *et al.*, 2016). Due to Agile methods promoting analysis, design, and development in short increments, slippage can be easily identified and addressed. This is not always the case when employing planned or phased project management methods, as they make it hard to judge the accuracy of the analysis, design and development until the implementation phase has been undertaken. Another advantage is the effective communication and sharing information that Agile methods facilitate, all project team members will be knowledgeable in all project areas, meaning that development will not become bottlenecked when a particular individual is indisposed.

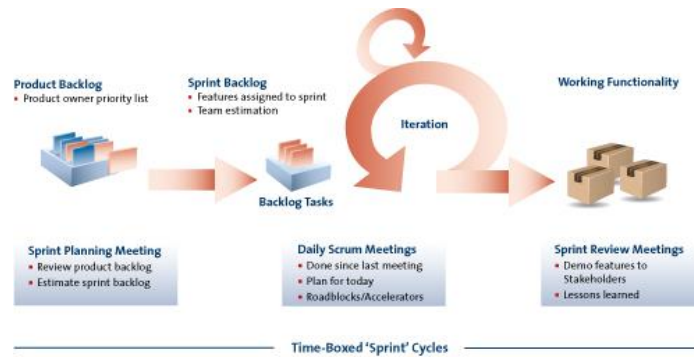


Figure 2-3: The Agile Process Model (Rana, 2009)

However, many project team members will find Agile method hard to employ. If there is a good rapport with work colleagues lacking, they will be struggling when attempting to facilitate effective communication, resulting in a sub-optimal knowledge transfer (Kerzner, 2017). And the closed stakeholder involvement needed throughout the project will result in project stalled until the stakeholder feedback is elicited.

PMBOK

The Project Management Body of Knowledge (PMBOK) is a collection of processes and knowledge areas generally accepted as best practice within the project management discipline (PMBOK® Guide, 2017). It is therefore a knowledge-based approach that covers the entire vast subject of project management. The PMI Guide to the PMBOK identifies and describes that subset of the entire PMBOK which is generally accepted as applicable to most projects most of the time. As an internationally recognised standard (IEEE Std 1490-2003) it provides the fundamentals of project management, irrespective of the type of project be it construction, software, engineering, automotive etc.

PMBOK recognises five basic process groups and nine knowledge areas for almost all projects. The basic concepts are applicable to projects, programs and operations. The five basic process groups are illustrated in **Figure 2-4**: 1) Initiating, 2) Planning, 3) Executing, 4) Monitoring and controlling and 5) Closing.

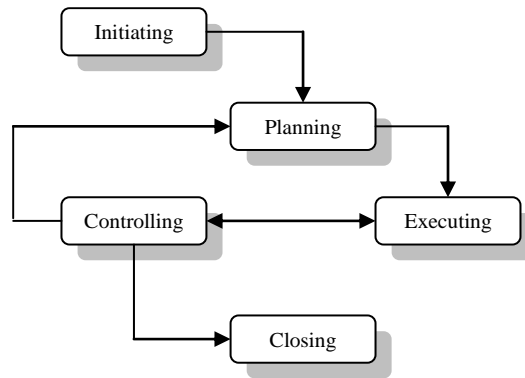


Figure 2-4: The PMBOK Process Model (PMBOK® Guide, 2017)

The PMBOK advantage is that it has very concise knowledge areas and easy to understand the concepts behind the theory (Yeong, 2007). The nine knowledge areas covered are full of useful processes, tools and techniques in project management. The five phases of project life cycle symbolise a typical project. However, PMBOK does not tell users how to apply to the project as it only stated what are required. For example, it tells users that a Project Charter is required but the recommended template is not covered. Therefore, it's very hard to capture, transfer and share the project knowledge, the same project processes may not even be used in the same organisation for a different project.

PRINCE2

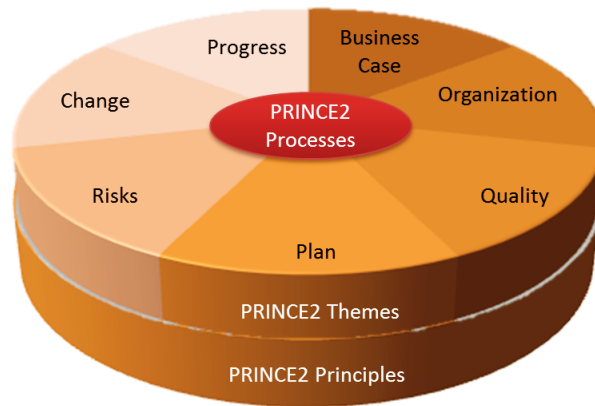
PRINCE (Projects IN Controlled Environments) is a structured and process-based approach for effective project management, it's designed to provide a framework which covers the wide number of activities and disciplines that are required within a project (Rupali & Kirti, 2017). PRINCE2 clearly defines the roles and responsibilities of the project team members and strongly focuses on the products that the project was established to deliver.

PRINCE2 has come increasingly popular in both the public and private sectors (AXELOS, 2017). Having become the de facto standard for project management in the UK (Bennett, 2017), PRINCE2 has spread beyond the UK to more than 50 other countries. Although it was originally developed for the needs of IT project, the method has been used on many non-IT projects. **Figure 2-5** shows the structure of the PRINCE2, which is based on seven principles:

1. Continued business justification
2. Learn from experience
3. Defined roles and responsibilities
4. Manage by stages
5. Manage by exception

- 6. Focus on products
- 7. Tailor to suit the project environment.

Seven themes: Business Case, Organisation, Quality, Plans, Risk, Change, Progress, and seven processes.



Highlights:

- 1. UK Government approved process oriented methodology
- 2. Reduces impact of risks like staff movement, decision making, stakeholder alignments etc

Figure 2-5: PRINCE2 Structure (AXELOS, 2017)

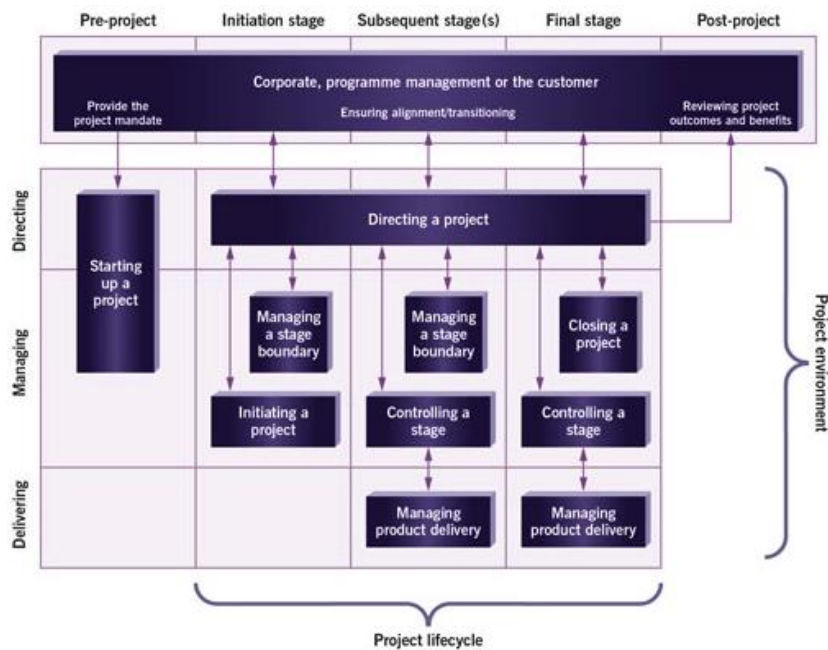


Figure 2-6: PRINCE2 Processes Model through the Project Lifecycle (AXELOS, 2017)

Like the RUP, PRINCE2 covers a project life cycle that has seven major specified processes running from starting up a project to closing a project. The seven processes which were

defined by the UK government are listed below and illustrated on the **Figure 2-6**. Each of these processes has their respective sub-processes.

1. Starting Up A Project
2. Initiating A Project
3. Directing A Project
4. Controlling A Stage
5. Managing Product Delivery
6. Managing Stage Boundaries
7. Closing A Project.

The PRINCE2 methodology suggests that as planning into the future is virtually impossible, it is sensible to plan in detail only for a limited time period. Different groups of people are often involved in projects: the stakeholders, the suppliers and the users.

PRINCE2 has a number of strengths. It provides benefits to the project managers and directors of a project through the controllable use of resources and the ability to manage business and project risk more effectively (AXELOS, 2017). Due to the process approach, it attempts to provide a controlled start, middle and end of a project, producing highly standardised projects, which share a common approach as well as a common vocabulary. Unlike the RUP, which needs to be tailored to a greater degree due to the numerous different disciplines within each phase, PRINCE2 provides project team members with a transferable skill and technology (undertake the same processes and use the same terminology) and anyone familiar with a method can quickly be brought up to speed on a properly applied PRINCE2 project. It has the advantage that it causes a degree of standardisation in an organisation (Project Performance, 2017). This has obvious benefits in corporate programme management, project staff training programs, and project performance and tracking systems. Another strength that can be identified is the embodiment of the best practices in project management, which allows the project manager to do his/her job without undue interference, yet can involve higher level managers should the project be deemed off-schedule. Flexible decision point facilitates easier management, allowing the project manager to review the project's progress against the business case throughout the project and adapt some of the work processes to try and remain on target. Compared with PMBOK, the PRINCE2 approach has the advantage that it is very prescriptive and provides the necessary techniques and templates for project manager to apply. Most of the templates are either available from the manual or the AXELOS website (AXELOS, 2017).

However, PRINCE2 does not cover people management, meaning that an inexperienced project manager may struggle with project relationships to detriment of the project. Another limitation to PRINCE2 is the lack of detail present in relation of running a project. For example, although PRINCE2 tells project managers that a project plan is needed, there are no details or examples regarding how to create one (Tomanek & Juricek, 2015), thus assuming that the project manager is knowledgeable in all necessary areas and must learn how to streamline the processes according to the complexity and environment of the project. In addition, although product based planning is a fundamental part of the PRINCE2 that provides a basic guide of doing product refinement, it does not prescribe a format for the product breakdown structure either provides a rule for validating the sub-products in practice.

This research aims to develop a method which is able to help project managers to share the project knowledge and generate project plan via product based benchmarking by adopting PRINCE2 approach but keeps it simple. This method incorporates the PRINCE2 principles and technique of product based planning but not following every last detail of the system. PRINCE2 is used as the basis of templates and as an example of an established project management system because it is readily available.

2.2. Project Planning

A project plan is defined as “a document framed in accordance with pre-defined scheme or method, describing how, when and by whom a specific target or set of target is to be achieved” (Bentley, 2005). Mayor (2005) argues that project planning is the most important stage in project management lifecycle. As noted in the previous section of management, it involves decisions about objectives as well as means, and decisions about conduct as well as results. At the planning stage the total resources, cost and time duration of a project is estimated and planned for. It is believed the successfulness of a plan determines the fate of the project. Sometimes plans fail, reasons for this failure are poor financial estimates, insufficient data when planning or project estimates based on the experience and guesses of project manager.

A good project plan will provide the following (Haughey, 2008):

- A realistic project timescale
- Details of resource requirements
- Validation of the estimated cost

- Identification of task slippage
- Early warning of problems

There are many approaches and techniques designed for project planning in project management literature, which can be divided into two main methods: “activities based planning” and “product based planning”.

2.2.1 Activity Based Planning (ABP)

Most popular project management planning techniques are activity based. A review of the PMBOK Guide (2017) reveals that activities and tasks are the unit of analysis in the core processes of project management, like quality management, time management, and cost management, and that their management and control is centralised. This is also supported by the description of Morris (1994) of the classic and still current project management approach as follows: first, what needs to be done; second, who is going to do what; third, when actions are to be performed; fourth, how much is required to be spent in total, how much has been spent so far, and how much has still to be spent. Central to this sequence is to identify the individual parts in a project. The process is the foundation for the detailed project plan. The purpose of this process is to decompose the project into small chunks.

Work Breakdown Structure (WBS)

Work break down structure is a project management technique which was developed in 1960s by the US defence (DoD and NASA). This is a traditional approach that has been used in many industries for a long time. The idea of WBS is to take an overall “work” of project and to break it down progressively into smaller and smaller chunks until it ends up with individual tasks, or work packages that can be estimated sensibly and assigned to team members (Cadle and Donald, 2014). It is believed that WBS not only defines the scope of work, but it also forms the backbone of every project. Without an effective backbone a project has no structure to plan and control all the parameters of time, cost quality, procurement and resources. WBS is an excellent tool for quantifying the scope of work as a list of work packages and it’s an essential tool for ensuring the estimate or quotation includes the complete scope of work. WBS is based on activities to make a project plan.

Critical Path Analysis (CPA)

The Critical Path Analysis (CPA) is a method used in the scheduling of project tasks. It shows the dependency between tasks so that the critical path - the path that must be followed if the project is to complete on time can be identified (Kerzner, 2003). This method shows a list of all the activities involved in a project, time duration of each activity, dependency between the activities and the longest time duration to complete the project. The critical path network diagram shows the activities on the critical path. A delay on the activities on the critical path will delay the whole project (NetMBA, 2008a). The activities of the critical path are closely monitored to ensure the project does not go wrong. It is clear that CPA is an activity-based scheduling tool too for project management.

Program Evaluation and Review Technique (PERT)

The Program Evaluation and Review Technique (PERT) is a network model that allows for randomness in activity completion times. PERT was developed in the late 1950's for the U.S. Navy's Polaris project having thousands of contractors. It has the potential to reduce both the time and cost required to complete a project (NetMBA, 2008b). The technique is intended to deal with the like hood that the single value given as the estimated time for completion of activities is going to have a degree of error associated with it. Instead of taking a single time, three times estimates for each activity are required (Harvey, 2003):

1. Optimistic time: how long the activity would take if the conditions are ideal
2. Most probable time: time if conditions were 'normal'
3. Pessimistic time: how long the activity would take if a significant proportion of the things that could go wrong did go wrong

The steps of PERT planning are very similar to CPA. With PERT the project expectation project completion date can be told. PERT is solely based on project activities too.

2.2.2 Limitations of ABP

Typical activity based project planning methods like WBS, CPA and PERT are discussed previously. In these methods, activities are used as milestones for the users to check the quality of the project deliveries. Graphical diagram is commonly employed by project managers to manage the project deliveries effectively such as Gantt chart and Microsoft Project (Microsoft®, 2016) uses activities to support project planning, allocating resources, tacking processes, managing time and budget and analysis workloads (Tang, 2008).

Although activity based approach is the traditional planning approach which has been widely used in many industries for a long time (Ling *et al.*, 2105), it has some limitations which cannot be ignored (Tang, 2008). Firstly, different people may take different activities to deliver the same product. They will plan and take preferred activities for the same product based on their own experience and preference. Consequently the experience and information is not easily sharable due to the fact that new technologies, process re-engineering and different personnel preferences may all affect the practices of conducting project activities, unless exactly the same project having exactly the same processes is been planned for, which is very unlikely. The number of projects who fall into this category is very limited as the new project must follow exactly the same activities of the previous project to share that information. Secondly, it is difficult to measure the quality of activities during the project at activity level (Phillips, 2016). The quality of activities can only be properly measured by the quality of their outcomes (i.e. deliverables or products). In addition, the vast amount of information which contains the best practices of working on certain products (deliverables) is not even captured in activity based planning processes (Ajelabi & Tang, 2010).

2.2.3 Product Based Planning (PBP)

Product based planning is a technique of PRINCE2 project management method for project planning (OGC, 2009). This technique looks at all the deliverables of a project and the component parts as products. A product may be a tangible one such as a document, piece of software or it may be an intangible such as culture change or change in work process.

When starting a plan, it can be quite hard for project manager to think of all the tasks that will need to be undertaken if the project is to meet its objectives. The PBP technique enables the project manager to “define what the project has to deliver”, “provide descriptions of the required products, the skills needed to develop the products, measurable statements of the quality required and how the presence of that quality is to be tested” and “objectively monitor and control progress” (AXELOS, 2017). If the project is to implement a new information system then the final product would be “working information system”. Note that there is seldom a single word descriptor for a product. There is usually a verb, normally in the past tense, describing the noun which helps identify the tasks and products that are its component parts. Example like you will think only of the finished vehicle if it’s called a car. Describe it as an “assembled car” and your mind immediately starts to think of the components.

The product at the very top of the PBS is the End Product, this is also the last product shown in the PFD. There are three types of product in PBS as shown in **Figure 2-7**: Simple Product, Integration Product and External Product. Products shown without other products underneath them are called Simple Products. All remaining products in the “middle” of the PBS are called Intermediate Products. There are two types of Intermediate Products:

1. **Collective Product:** These are not real products, and just help the planner to include all the real products underneath. So use the words Group or Grouping to describe them.
2. **Integration Product:** These are real products, and the products underneath them are combined in some way to become the Integration Product. The shape of an Integration Product is the same as a Simple or End Product.

External products are those that already exist or are applied from external sources

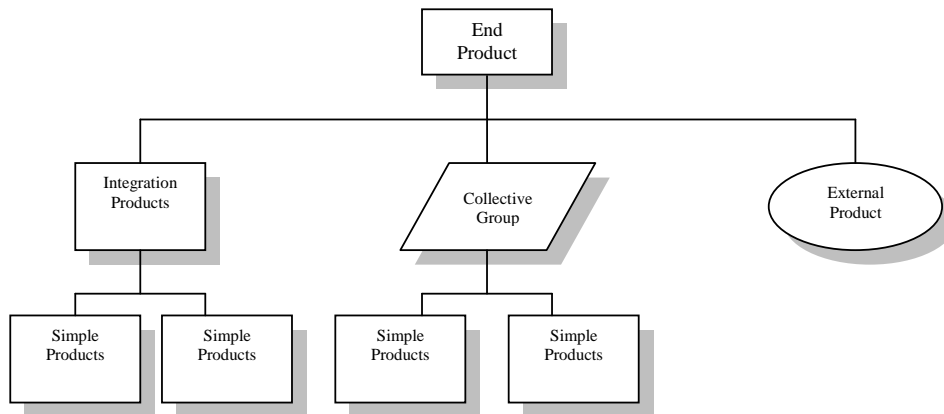


Figure 2-7: Symbols for Creating a PBS

The PBS is a hierarchical diagram and does not show sequence. Thus the last task of product based planning is to create the PFD which shows “the sequence of creation of the products” (OGC, 2009), and it is drawn with arrows showing sequence and dependencies. It gives a logical sequence to what the project is set to achieve. The PFD is created from the PBS and indicates the order or sequence in which the products will be created and the dependencies between them.

2.2.4 Advantages of PBP

Compared with activity based approach, the advantages of product based planning (Litten, 2017) technique are summarised below:

Firstly, product based planning focuses on the products to be delivered and their quality required (OGC, 2009). It ensures that the project's focus is on what is to be achieved rather than how, in other words on the ends rather than the means. This focus on products makes it possible to measure the quality of products against the Product Description of the End Product and the Simple Products in the middle of the project.

Secondly, with using product based planning technique, different practices and their information can be easily shared (Ajelabi & Tang, 2010) with other projects with similar products through benchmarking technique. Thus product based approach is more easily to achieve automated resource estimation. This more sophisticated planning method can be a guideline for the new project management applications designed to efficiently support the project plan creation and the adjustment based on the practices from historical data. With this method, project management applications can offer better guidance to project managers and even programme managers; because it can assist in shaping the plan and the breakdown of global project resource estimates into product and activity efforts; tracking project progress with alert mechanisms, thus ensuring the project will meet its goals in terms of the PRINCE2 main principles.

Thirdly, projects with activity based planning are difficult to compare as different people may have different implementation approaches (as shown in **Figure 2-8**). The final products of project are the best way to do product comparison (Abhijat, 2009). With using product based technique, not only the final product can be compared, but the Simple Product between different projects can also be compared as the products are the main focus in that case. The main attributes of the product like cost and time duration can also be compared among projects.

Fourthly, with employing product based planning, it's more realistic and productive for project managers to plan (Bennett, 2017) for a "green" area of work, this is because it's difficult to know what exactly to do (i.e. activities) from the beginning of the project in many cases. However starting from considering what has to be delivered will achieve a more rational plan, especially when plan time is consuming.

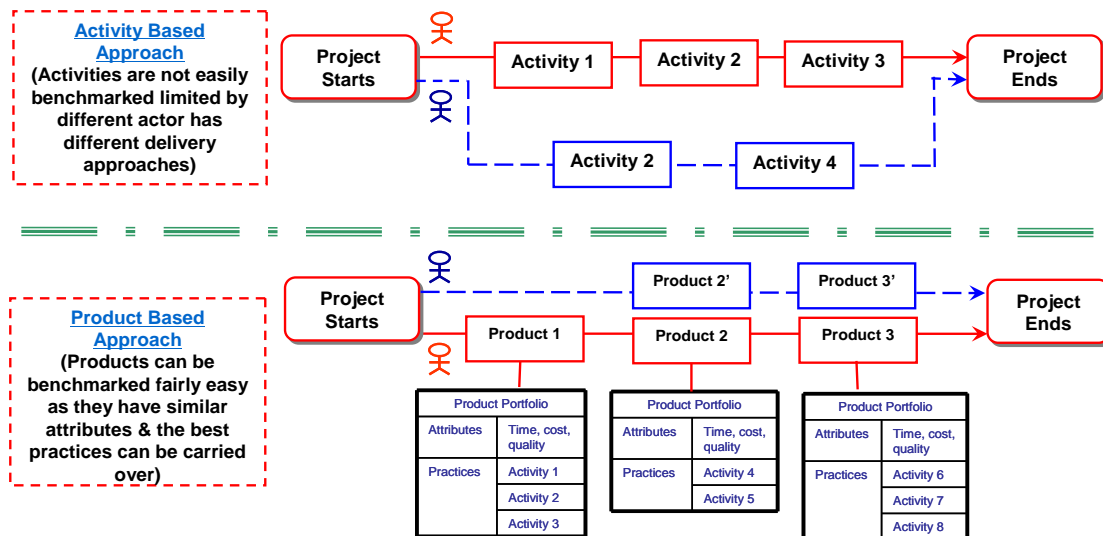


Figure 2-8: Comparisons of Activity Based Approach and Product Based Approach

Fifthly, the focus on the project products will make the project stakeholders focus on the main objective of the project that directs their minds on their expectation of the products and their qualities (AXELOS, 2017). The management level can focus on the issues most relevant to them. The senior management team owns the “Why” question which is close to the strategy, business case, external environmental factors that may affect the business; The Project managers takes charge of “What ”question, which focuses on the product deliverables and the junior or technical members concentrates on the “How” to deliver the products on time with requested quality.

Finally, a significant advantage of product based planning is associated with project reporting. It facilitates a more precise control of the scope of the project and to focus only on what is essential to meet the Business Case. Products are either completed or not; activities can be 95% complete and remain at that state for a long time whilst work is taking place (Tomanek & Juricek, 2015). One tends to forget those important activities that have to be conducted to complete a project - much of this work is document control activities associated with project closure. Product based planning captures them all to reduce the chance that any will be overlooked.

This is of significant importance to this thesis, as it explained why product based technique best suits project information sharing, and how well it will adapt to the context of the research.

Having reviewed the theoretical foundations of project management, in particular, product project planning which is the focus of this thesis.

2.2.5 Challenges of PBP

Although PBP has some advantages to use historical project information for automated resource estimation and benchmarking, AXELOS (2017) does not give a clear guide on how to break down projects into products either provides a rule for validating the sub-products in practice, it only states that a project just needs to be broken down three times into four levels. Furthermore, the project management approach could be different from organisation to organisation, and from person to person, the way how to break project into proper sized sub-products could be varied. Therefore, this thesis introduces a regulation to refine product and validate the results when product based planning technique is applied.

On the other hand, after project is planned, the followed step is to execute the project which involves taking the actions necessary to ensure that activities in the project plan are completed. How to ensure the actual running of the project on a day-to-day basis, monitoring progress and making changes to keep on track for delivering the final product is another challenge. Monitoring and controlling is the process of measuring progress toward project objectives, monitoring deviation from the plan, and taking corrective action to match progress with the plan. Meanwhile various interested parties will also wish to receive reports on the progress of the project. To monitor and report progress efficiently, a novel framework with an integrated product benchmarking and recommendation mechanism is developed in this thesis for associating project planning and collecting information on the resources needed.

During the project monitoring and controlling phases, project team members always need to submit a brief status report to report what is going on and why. This extra information helped team members reflect on the project's progress and identify areas in need of improvement. The closure process involves gaining stakeholder and customer acceptance of the final products and services and brings the project to the end. It includes verifying that all of the deliverables are completed and reflecting on what can be learned and to improve future projects. In addition to all kind of project status reports, an important tool for monitoring and controlling the project is to use project management software. This research takes into account this issue and develops a project management tool to track and monitor the project progress based on the plan, and collect the extra information for future project plan and improvement.

2.3 Project Information Sharing

Having examined some of the key theoretical aspects of project management, this section turns to the issues of the practice of sharing information in project management. In modern times, the projects' members must create new knowledge by being engaged in a learning experience. Learning-by-doing occurs when a problem solver associates plans and actions with results to develop procedures to accomplish positive results and avoid negative results (Anzai, 1987). Based on Drucker's (1993) and Nonaka and Takeuchi's (1995) definition of the knowledge-based organisation, building the organisation's knowledge is one key to long-term survival of organisations. As a project manager, s/he must rely on the organisation's knowledge to meet and increase project management performance (Lee *et al.*, 2010).

Furthermore, project organisations must continuously improve their knowledge through the organisational learning and knowledge sharing process across different projects and sectors. Each project has different plans, results, problems, and successes that offer an opportunity to learn from. By integrating and sharing these experiences and learning across projects, the project organisation will have a greater knowledge base to pull from and then use for future business activities. The issue of how better to share knowledge such as best practices across teams and between knowledge workers therefore becomes of central concern of the project managers.

In project management, knowledge is created from and during the exercises of people planning and completing the project, the practical information collected from completed projects with certain patterns and stored with pragmatic formats will become the explicit knowledge which can be managed and powered. As the major part of the project knowledge, the stored project information is the best transformation and approach to be integrated and reused for all project processes. The choice of the overall approach depends on the way in which the organisation manages the projects and delivers its products and services.

Review of project information sharing literature (Dursun & Ford, 2015; Kucharska & Kowalczyk, 2016; Kovach *et al.*, 2017) shows strong emphasis on knowledge management and sharing. This section provides an overview of the theories and discusses part of the theories that relate with project information sharing. Also the concept of project portfolio management and challenges of project information sharing will be discussed.

2.3.1 Knowledge and Information

Throughout the literature review of project management theory there appears to have been an incremental rise in the influence of knowledge (Sheen and Ryan, 2004). There are various descriptions to what knowledge is - several researchers have given their different views on it. Based on the work of Nonaka (1994) and Huber (1991), knowledge is defined as a justified personal belief that increases an individual's capacity to take effective action. Action in this context requires physical skills and competencies (e.g. playing badminton, or taking project activities), cognitive or intellectual activity (e.g. problem solving), or both.

The definitions of knowledge found in the information systems literature further make a distinction among knowledge, information and data. Vance (1997) defines information as data interpreted into a meaningful framework whereas knowledge is information that has been authenticated and thought to be true. Maglitta (1996) suggests that data is raw numbers and facts, information is processed data, and knowledge is "information made actionable". Knowledge, embedded in users' minds, is thus a prerequisite. Users can instantiate some of this knowledge as information, which is explicit and processable. By examining the structure of this information, users may finally codify it into pure data. In this case, knowledge can be defined as all information that is relevant for action. The greatest challenge in business today is to link the content (information) with the context (action) (Dalkir, 2005).

Davenport and Prusak (1998) describe knowledge as a "a fluid mix of framed experience, values, contextual information and experts insights and grounded intuitions that provides a framework for evaluating and incorporating new experiences and information. It originates and is applied in the minds of the knower". In project environments, it often embedded not only in documents or repositories, but also in organizational routines, processes, practices and norms. This definition highlights two important type of knowledge: explicit knowledge and tacit knowledge which were given by Nonake and Takeuchi (1995).

Explicit knowledge is knowledge that has been articulated in formal language and can be easily transmitted among individuals. It can be expressed in scientific formulae, codified procedures or a variety of other forms (Stenmark, 2002). Choo (1998) suggests that explicit knowledge is knowledge that is made manifest through language, symbols, objects, and artefacts. Explicit knowledge can further be object based, i.e., software code, databases, technical drawings and blueprints, chemical and mathematical formulas, business plans, and statistical reports, or rule based routines and procedures. Organisations tend to depend

primarily on this sort of explicit and articulated knowledge, written down in memos and illustrated with graphs and used in decision-making processes, or institutionalised as operating procedures. Tacit knowledge, on the other hand, refers to that knowledge which is embedded in individual experience such as perspective and inferential knowledge, which making them difficult to communicate or share with others (Nonaka and Takeuchi, 1995). Both explicit knowledge and tacit knowledge are important for the project management. They are recognised as providing different values to the project management. Knowledge such as project management skills or operational experience needed in their activities and processes are shared, as it is expected to be known (Kimpeler, 2001).

Although knowledge cannot be simply defined as the collection of information, Alavi and Leidner (1999) argued that knowledge is not a radically different concept than information, but rather that information becomes knowledge once it is processed in the mind of an individual - the word of “tacit” knowledge from Polanyi (1962) and Nonaka (1994). This knowledge then becomes information (“explicit” knowledge) again once it is articulated or communicated to others in the form of text, computer output, spoken, or written words or other means. The recipient can then cognitively process and internalise the information so that it is converted back to tacit knowledge. The concept above is adopted throughout this research work.

In a word, collected information itself is of little value, only the information is actively processed in the mind of an individual through a process of reflection, enlightenment, and learning can be useful (Alavi and Leidner, 1999). In addition, knowledge is of limited organisational value if it is not shared. Within organisations, knowledge management refers to a systemic and organisationally specified process for acquiring, organising, communicating and sharing both tacit and explicit knowledge of employees so that other employees may make use of it to be more effective and productive in their work. In this thesis, work is emphasised on how to share the information of best practice among the project organisations. The best practice is explicit knowledge which should be captured, processed and shared through a pragmatic way to optimise the management of organisational resources, which is discussed further in later chapters.

2.3.2 Knowledge Management

Knowledge management like knowledge has been defined in many different ways. This thesis has extracted the commonalities that exist in the several definitions that are appropriate to this

research context (Power *et al.*, 2015; Liebowitz & Frank, 2016; Dalkir, 2017). Knowledge management is seen as a strategy (or practice, systematic process, set of policies, procedures and technologies) that capture, distribute, and effectively use knowledge. Knowledge management therefore implies a strong tie to organizational goals and strategy, and it involves the management of knowledge to fulfil organizational objectives which creates value for the organization.

2.3.3 Shared Information in Project Management

Literature on knowledge management provides a definition of knowledge sharing. According to King *et al.*, (2008) knowledge sharing is the dissemination of knowledge that is used in direct communication techniques such as databases to communicate knowledge between a sender and the knowledge recipient. In discussing knowledge sharing in project based organisations, it is important to remember the difference between knowledge and information defined in last section. Knowledge was stated as implying explicit knowledge that can be formulated and transferred. While information was stated as an asset that is required for performing project activities. Following on this, Beverne (2002) in an article argued that knowledge can only be communicated after it has been downgraded to information. According to him, knowledge cannot exist outside of a human brain. Therefore knowledge cannot be transferred to any recipient. From this analogy, it can be inferred that what is referred to as “knowledge” stored in database for re-use by other projects is in fact “information”.

There are also many different interpretations of what exactly knowledge in project means and how to use its potential power effectively. This research adopts the statement from Kotnour and Landaeta (2002) that project knowledge can be viewed as more than one piece of information in a pattern from which explicit inferences and predictions can be made to support decision-making and action taking in the project organisation. Therefore the appropriate term for knowledge sharing in project based organisation should be information sharing.

All communications and knowledge processes in project are based on information. Information itself is a process which consists of semantic, pragmatic and syntactic layers (Kimpeler, 2001). It becomes knowledge if it's mentally processed, could be powered by instruments such as IT, and it has to be organised by rules that are set by its users. Project managers need to address and develop appropriate methods of information sharing during the project management. However too often it is assumed that information freely exists and can

be captured and shared between contexts. Such assumptions hide complexities and problems of information sharing (Almahamid *et al.*, 2010).

Having established that “information” rather than “knowledge” is the useful knowledge for sharing among projects in project based organisations, what constitutes as “information” for sharing in project based organisations needs to be investigated. The granularity of “Information” contained in most knowledge management systems are about the activities taken to deliver projects. The project delivery information stored in knowledge management systems is dictated by the principles adapted to plan the project.

2.3.4 Challenges of Project Information Sharing

Because of too much information can be collected and identified during and after project completed, there is a need of an information management approach to analyse typical attributes of projects in project management process include each project's total expected cost, consumption of scarce resources (human or otherwise) expected timeline and schedule of investment, and relationship or inter-dependencies with other projects in the project portfolio.

Fernie *et al.* (2002) argued that project information by itself is a problematic esoteric concept that does not lend itself easily to codification. Specifically information in project management possessed by individuals, presents particular methodological issues. It is argued that knowledge is highly individualistic and concomitant with the various surrounding contexts within which it is shaped and enacted. These contexts are also shaped as a consequence of knowledge adding further complexity to the problem domain. Current methods of information capture transfer and sharing fall short of addressing these problematic issues. This research attempts these problems and proposes an alternative method of information sharing drawing on data and observations collected from its application.

Moreover, in the absence of information sharing mechanisms for application within and across sectors, project managers in each sector have to “reinvent the wheel” when each time of establishing a new project. The notion of learning and benchmarking from other projects is increasingly central to the best practice agenda in many industries such as constructions and engineering. Of course it is assumed that the capture and transfer of managerial information between industrial contexts is unproblematic. Applying best practice means learning from and through the experience of others. One way of doing this is through benchmarking, which allows organisations to compare their business with other successful businesses to highlight areas where their business could improve. To benchmark the project practices, a certain

criteria including spent time, cost, quality achieved finally and project context must be selected. Currently, best project practices are made explicit in terms of persistent data from operational processes or activities, but underlying influencing factors remains implicit. The risk of such practice is the project plan and estimation will not take account of other factors such as different environment, technology advances and different customer profiles.

Despite the clear benefits of project information sharing application in project based organization, evidence is accumulating that the practice is not very helpful (Von Zedtwiz, 2002; Atkinson et al., 2006 Whitty and Duffield, 2015). For example, Keegan and Turner (2001) studied eighteen different project based organizations and found no single company expressed satisfaction with the project information sharing process. Milton (2010) also found that out of seventy-four organizations that attempted project information sharing, sixty percent were dissatisfied. O'Dell and Hubert (2016) found that whilst the project information sharing is popular, it fails to deliver the intended results as lessons are identified and are often not followed through or applied within the project organization. Atkinson *et al.*, (2006) also stated that project information sharing “is a popular term in project management literature and amongst practitioners, yet it often masks payment of lip service only to the idea of learning from experience. The capture and re-use of previous experience and historical data from one project to another is generally considered as something that should be done but it often goes no further than capture (Chika *et al.*, 2006).

2.3.5 Project Portfolio Management (PPM)

Information sharing plays a crucial role in project management processes. Project knowledge such as project practices or operational experience needs to be shared to improve the efficiency of planning and control process. The best practice is the explicit knowledge which should be captured, processed and shared through a pragmatic way to optimise the management of organisational resource. But shared knowledge requires a common system of signals, codes and ways of expressing (Kimpeler, 2001; Peerasit 2015). Furthermore, although the detailed information and gathered from previous projects will be critical for characterising and planning the “to-be” process of project, that information may be buried in piles of archived documents which can be increasingly difficult to sift and utilise productively. Project portfolio has been brought into this field aiming to improve the information sharing and management among different projects.

Project portfolio management (PPM) is such a management process to achieve the above goals. PPM is designed to help an organisation acquire and view information about all of its

projects, then sort and prioritise each project according to certain criteria such as strategic value, impact on resources, time spent, cost and quality and so on, while making the best use of limited resources (Greer, 2009; Amelia *et al.*, 2016). The objectives of PPM are similar to the objectives of managing a financial portfolio. More importantly, PPM aims to support ongoing measurement of the project portfolio so each project can be monitored for its relative contribution to business goals. If a project is either performing below expectations (cost overruns, benefit erosion) or is no longer highly aligned to business objectives (which change with natural market and statutory evolution), management can choose to decommit from a project and redirect its resources elsewhere (Cooper *et al.*, 1998). But PPM can't be effective without solid, well-documented project plans, accurate estimates of resource requirements, and accurate information about actual resources consumed.

Project portfolio is a fundamental part of PPM. A project portfolio is a set of projects in a project-oriented organisation that holds at a given point in time and the relationships between these projects (Gariesis, 2008). It is a term that refers to an organization's group of projects and the process in which they are selected and managed. (Michael *et al.*, 2015).

A typical project portfolio is activity based, usually collects the following information:

- The project name, type and description
- Internal and external resource required for each project
- Number and skills of people required
- Estimated time to complete a project.
- Estimated cost of each project
- Activities undertaken of each project
- Actual duration for completion of a project
- Actual cost of a project

Information in project management captured and shared through a systemic way could become explicit knowledge if it's processed and codified. The explicit knowledge above could be collected from completed projects and stored in the project portfolio data repository. The data repository contains information about both current projects and the actual results of previous projects. This information will assist a project manager when planning for a new project which has been done previously. With using the information from a previous project, the project manager can make a better plan based on the actual results of the previous projects rather than only on his/her experience.

Theoretically, the information collected in activity based project portfolio should be re-used to establish a set of values and techniques to ensure visibility, standardization, measurement and process improvement for other projects. However, in practice, the granularity of for each activity and how to share the information detail with other projects is a challenge (Tang, 2008). As the typical activity based project portfolio normally contains the general information at the project level, only the information like time and cost for project activities are measurable, the quality of activity is difficult to be measured and collected which means the quality of activity is not easy to be benchmarked. The detailed information collected at the activity level can be useful for future project planning only when the same work practices are followed. Tireless attempts have been made by many researchers to standardize work processes (Bowman, 1995; Gregory, 1996; Walters and Lancaster, 1999; Ghasemzadeh & Archer, 2000; Rolf, 2008; Michael et al., 2015; Peerasit, 2015) aimed to overcome the difficulties for activity based project portfolio information sharing.

Therefore, the information stored in traditional project portfolio is based on activities hence has the same limitation of activity based planning; a new project must follow exactly the same activities of the previous project to share its information. To overcome this limitation, a product based project portfolio is proposed in this thesis to contain more detailed information of each products apart from time, cost, resource and dependencies, such as quality criteria, constrains and activities underneath. This information is very useful when compare with same or similar historical products for planning a new project or generating relevant business intelligence. This approach is based on the product based planning technique from PRINCE2, and it is discussed in details in Chapter 3.

Although product based portfolio can improve the limitation of activity based portfolio, sharing project best practice through project product portfolio is a multi-criteria decision making process to deal with optimisation of conflicting objectives such as quality, cost and delivery time (Benyoucef and Canbolat, 2007; Hasan *et al.*, 2008; Pérez & Gómez, 2014; Clifford, 2016). Such approach in project management experiences a main problem with using benchmarking of sharing information among different projects is that projects by their very nature are unique (Barber, 2004; Marija *et al.*, 2015).

This thesis proposed an integrated mechanism to ensure the right products are selected based on products of which attributes are important for customer criteria during the project planning stage, it enables the inclusion of both quantitative and qualitative factors extracted from product based portfolios in the decision process. This method also attempts to clear out

ambiguities and variations that are present in the current project benchmarking methods and develop an effective and sound way for sharing project knowledge.

2.4 Benchmarking for Information Sharing

2.4.1 Best Practice Benchmarking

To save unnecessary resources and have a satisfied project plan, previous experience and historical data could be used from similar projects such as how long it took, how much it cost, what the problem areas were and what the successful areas were. The ultimate purpose of planning is to build a model that enables project managers to predict which exercises and resources are critical to the timely completion of the project. Strategies may then be implemented to ensure that these exercises and resources are managed properly, the ensuring that the project will be delivered both on time and within budget.

Best practice is brought to this area to improve the efficiency of planning and control process as well as substantiate existing data on project success to improve customer confidence. Best practice often refers to a way of doing something that has already been tried and tested many times elsewhere, or an innovation in practice that is recognised by peers as a more effective method or approach, fitting with the circumstances of a situation. Utilising best practice for project planning is also a process used in project management, in which develop project plans on how to adapt specific best practices, usually with the aims of saving time and cost, and increasing some aspects of project performance.

Frequently to utilise the best practice in both public and private sectors is to benchmark against a similar and previous project by using historical data. Benchmarking is also called as “best practice benchmarking”. Benchmarking is a technique to allow the company to bid for projects from a consistent cost basis, using evidenced-based costing, timing and project planning information gained from previous successful projects. Thus detailed project information need to be collected beforehand benchmarking. Benchmarking is also a powerful and effectual method to assist companies or organisations to improve their performances by identifying the strengths and weaknesses of their businesses when compared with their competitors. Direct and obvious measures can be identified to improve the productivity and quality. These measures can be used to contribute to the organisational strategy. Benchmarking can also assist project organisations to collect data or information to monitor

the status of the project. The term benchmarking refers to the actual activity of establishing benchmarks and “best” practices (Davies *et al.*, 2000).

However, current project benchmarking experiences a main problem with using benchmarking of project practices between different projects is that projects by their very nature are unique (Barber, 2004). All projects will involve some elements that cannot be directly translated from one to another, especially those projects planned based on activities. Furthermore, benchmarking has often been found deficient because it highlights the performance gaps without giving the reasons for these gaps. Sometimes, the performance gaps identified through benchmarking have more to do with the differences in the way the organisations measure and track the performance of their systems, rather than any meaningful differences in the way each manager controls his or her project (Cadle and Yeates, 2014). Project management today is seen as a systematic process. The lack of comparable objectivity is a difficulty that is well recognised with in project management evaluation exercises. If the project processes or activities are taken by project managers differently, then the evaluation of the managing of differing processes will be flawed, the information cannot be easily benchmarked and reused for the new project unless the new project will take exact same activities or processes as the previous one.

Thus, product based portfolio benchmarking and recommendation techniques are employed in this thesis, only similar products or deliverables can be benchmarked efficiently so that the product information and best practices can be reused for future project. Of course, when benchmarking the practices of projects the underlying influences of comparable deliverables must be similar.

2.4.2 Benchmarking Criteria Selection

Benchmarking criteria selection in project management is a process to select key factors from specific aspect of project management based on project goals or key requirements from stakeholders through measurement. Fenton & Pfleeger (1997) defined measurement is the process by which numbers or symbols are assigned to attributes of entities in the real world in such a way as to describe them according to clearly defined rules. Thus measurement captures information about attributes of entities. An entity is an object or an event (e.g. a product). An attribute is a feature or property of an entity (e.g. quality of product etc).

However, there is no single benchmark that will cover all the aspects of project management evaluation. The best method of benchmarking the management of a project will be by using

the best set of matching criteria for each aspect of the management process being evaluated. The benchmarking criteria of product will reply on the articulation of user requirements and follow closely the organisational goals. For example, the criteria for product benchmarking could include spent time, cost, quality achieved finally must be selected, and size, weight, and product context could be selected as alternatives depend on the specific user requirements in specific projects. This thesis is focus on benchmarking of product based project portfolios to improve the project planning and information sharing, relevant benchmarking criteria will be obtained from user requirements based on project goals.

2.4.3 Benchmarking Approaches

Sharing best practice through project portfolio is a multi-criteria decision making process. Such an approach in project management experiences a significant problem with the use of benchmarking among different projects is that natures of the projects are unique (Orouji, 2016). As the benchmarking criteria are derived from business context and customer requirements in relation to performance indicators, determining the criteria is a large challenge.

There are many benchmark approaches available. Here are some most commonly used approaches to assist best practise benchmarking (Kerzner, 2018) and decision making:

2.4.3.1 Ratio-based Metrics Approach

This kind of approach uses matrix to calculate the ratios of the benchmarked object (Greninger *et al.*, 1996). For example, it is possibly a better approach to ask a user for the company's turnover and the number of employees, and let the system calculate turnover per employee, rather than to ask how much the turnover per employee is directly from company. In this case number of employee and turnover appear in the questions, while turnover per employee, as a measure that better describes a company's productivity, appears in the report. Suchlike a measure is called a ratio in the system.

2.4.3.2 Cost-based Metrics Approach

This approach is to compare the ratio based on cost, for example distributed cost per unit shipped, or distribution cost as a percent of sales, this is also the very original benchmark approach especially is useful for those cost driven business performance (Greenberg, 2003).

The above two approaches are using quantitative data for benchmarking, they are efficient and good for most relative simple cases, but they are not good enough when there are many metrics referenced across project organisations.

2.4.3.3 Quartile Approach

The choice of using which benchmark approach is decided by what kind of format to define the best practice, i.e. some companies that are defined 100% efficient, while others' best practice are being set at 75%, and whether the benchmark will involve multi-criteria, multi-input and output. Quartile approach entails collecting attribute values in ranges corresponding to quartiles and converting it to quartiles for output purposes (Samiran *et al.*, 2011).

In general, the concept of quartiles is to arrange the data in ascending order and divide it into four roughly equal parts. The upper quartile is the part containing the highest data values, the upper middle quartile is the part containing the next-highest data values, the lower quartile is the part containing the lowest data values, while the lower middle quartile is the part containing the next-lowest data values.

Quartile approach is good for ordinal data and more stable than the range because it ignores other range of the values (Goswami & Chakrabarti, 2012). In most cases of engineering industry, benchmarking is among a large amount of data the average isn't giving the expected results, project users would like to see a range of benchmarked results. In addition, quartiles approach provides quantitative information that assists user to review product portfolios (financial or project) in a fast and efficient manner, thus quartiles approach was chosen as the benchmark method in the thesis.

However, sometimes Quartile is harder to understand, as it doesn't use all the information (ignores three quarters of the data-points, not just the outliers if it requires upper quartile data only for benchmarking for example), and tails almost always matter in data and these aren't included. Outliers can also sometimes matter and again these aren't included. The most important, it cannot cope with the case if the benchmark will involve multi-criteria, multi-input and output for decision making.

2.4.3.4 Data envelopment analysis (DEA)

Another common forms of quantitative analysis used in metric benchmarking is Data envelopment analysis (DEA), which a linear-programming-based methodology for evaluating relative efficiencies of decision making units (DMUs) with common inputs and outputs. The

DMU performance efficiency can be measured by a weighted sum of outputs to a weighted sum of inputs. It has been demonstrated to be effective for certain types of benchmarking (Liu *et al.*, 2016).

DEA a multi-input, multi-output method that focused on the ranking and analysis of the benchmarking efficiency of multiple DMUs such as industries, universities, hospitals, cities, facilities layouts, etc (Zhu, 1998, Cooper *et al.*, 2011, LaPlante & Paradi, 2015). DEA technique has also been used in measuring the efficiency of project management methods. Trindade *et al.*, (2015) used DEA method for measuring project management efficiency of a Portuguese electricity distribution utility.

However, there are crucial problems related to mixing multiple dimensions by using DEA in the project benchmarking analysis. For instance, consider a DMU performing two different activities; the DMU could be found efficient in the first activity but inefficient in the second. Because the relevant inputs and outputs for individual activities are not directly comparable, the analyst would have to run two DEA models for the services (Ashoor, 2012).

Kwon *et al.*, (2017) proposed an innovative three-stage model using DEA and backpropagation neural network (BPNN) for supporting 'better practice' benchmarking as contrasted with the traditional 'best practice' benchmarking. They reported that DEA models could provide the capability of setting optimal objectives, but the drawback of the standard DEA method was its inability to give actionable targets necessary for incremental improvement (Oroujia, 2016).

2.4.3.5 Analysis Hierarchy Process (AHP)

Analysis Hierarchy Process (AHP) provides a flexible and easily understood way of analysing complicated problems (Drake, 2016) such as performance benchmarking with both qualitative and quantitative factors taken into consideration. It is multiple criteria decision-making technique that allows subjective as well as objective factors to be considered in the decision-making process.

The AHP enables decision makers to take into account both multiple quantitative and qualitative criteria, to derive priorities for the criteria and to find out the preference priorities for each alternative DMU with regard to each criterion. The procedure for using the AHP can be summarized below:

- 1) Firstly is to build a hierarchy for the decision. This is also called decision modelling and it simply consists of building a hierarchy to analyse the decision. By structuring the problem in this way it is possible to better understand the decision to be achieved, the criteria to be used and the alternatives to be evaluated. This step is crucial in more complex problems, and it is possible to request the participation of experts to ensure that all criteria and possible alternatives have been considered.
- 2) Secondly is to derive the relative priorities (weights) for the criteria, as not all the criteria will have the same importance. It is called relative because the obtained criteria priorities are measured with respect to each other. A set of comparison matrices of all elements in a level with respect to an element of the immediately higher level are constructed. The pair wise comparisons are given in terms of how much element A is more important than element B, for example. The preferences are quantified using a nine – point scale.
- 3) The next step is to evaluate each of the elements with respect to these criteria. In the technical language of AHP, the alternatives will be pairwise compared with respect to their covering criteria. The pair wise comparisons generate the matrix of rankings for each level of the hierarchy after all matrices are developed, then all pair wise comparisons and Eigen vectors (relative weights) are obtained.
- 4) Finally use the priorities obtained from the comparisons to weigh the priorities in the level immediately below, and do this for every element. Then for each element in the level below add its weighed values and obtain its overall or global priority. Continue this process of weighing and adding until the final priorities of the alternatives in the bottom most level are obtained.
- 5) Once the above steps have been completed, a decision can be made which is to compare the overall priorities obtained and make a clear choice.

AHP has been previously used (Eyrich, 1991). His application was for benchmarking computer-integrated manufacturing (CIM) sites, and AHP was basically used for determining the success factors of the corresponding requirements and their importance for a best-of-breed CIM site. Korpela and Tuominen (1996) used AHP for benchmarking logistic operations through the seven steps approaches. However, effectiveness of benchmarking depends on the use of tools for collecting and analysing information and deriving subsequent

improvement projects. Dey (2002) and Mohamed (2010) used AHP technique for benchmarking project management practices. The entire methodology has been applied to benchmark project management practice of the public sector organisations. While his benchmarking model by using AHP was to determine problems and issues of project management in the public sector and suggest improvement measures for effective project management, rather than improving the information sharing during the project management processes. On the other hand, AHP requires data based on experience, knowledge and judgment which are subjective for each decision maker (Kambiz *et al.*, 2012). Song and Kang (2016) also addressed that ranking values vary according to the form of hierarchy structure and it is difficult to maintain consistency itself among responses. If the number of comparisons can be reduced, a comparison within a single level is optimal, and if comparison can be made while the priority among entities is maintained, consistency may be automatically maintained. A further disadvantage of this method is that it does not consider risks and uncertainties regarding the project performances.

2.4.3.6 Hybrid Method - AHP and DEA

Since research that examines the use of standalone mathematical programming technique to aid multi decision making is limited, the AHP and the DEA analyses have been utilised together to solve some multi-criteria decision making and quality problems since later last century. Shang and Sueyoshi (1995) have used the AHP, a simulation model and the DEA analyses for selecting flexible manufacturing system for a manufacturing organization. In their approach, both the AHP and the simulation model are used to generate input figures for the DEA-model. Sinuany Stern *et al.* (2000) extended the DEA analysis beyond the mere classification of efficient/inefficient to a full ranking, by incorporating AHP. Yang and Kuo (2003) also proposed an integrated approach to use the AHP and the DEA together to solve the issues of qualitative performance measures and the efficiency evaluation of the total quality management activities. Guan & Chen (2013), Markabi & Sabbagh (2014) and Girginer *et al.* (2015), proposed their hybrid methods of using AHP and DEA for efficiency analysis of surgical services, evaluating and selecting efficient suppliers, and coordination research on urban ecosystem. In these models, each DMU or alternative can freely choose its own favourable system of weights (Markabi & Sabbagh, 2014) to maximize its performance. Nevertheless, this freedom of choosing weights is equivalent to keeping the preferences of a decision maker out of the decision process (Kambiz *et al.*, 2012). AHP has also been a target of criticism because of the arbitrary nature of the ranking process in these models. Thus the problematic issue of confronting the contradiction between the objective weights in DEA and

subjective weights in AHP (Pakkar, 2016) needs to be aware when applying the hybrid methods.

Despite the criticality of the problem above, very little work of using integrated mathematical programming techniques has been conducted on the information sharing in project management area, especially by benchmarking and recommending best practices.

2.5 Summary

In this chapter, the fundamental background of project management was introduced firstly. Then information sharing in project management was discussed in different aspects. A distinction between knowledge and information was given. It also presented the concepts of project and information sharing as well as comparing the traditional management methods with PRINCE2 whose principles and techniques will be adopted in the thesis to contribute to solve the information sharing problem in project management. It is recognised that the starting point for a good project planning is a full understanding of the business requirement and scope. Then it introduced conventional methods of project planning and product based planning method. The main advantages and challenges of product based planning method were also illustrated. As the main technique for constructing the project information sharing model in this thesis, the product based planning method also leads to the product based portfolio management. This chapter also looked at the state of arts of best practice benchmarking techniques in project management and the challenges that product based project portfolio face. The product based planning and product based project portfolio management are the two key techniques used in this thesis to improve the efficiency of information sharing in project management.

Next chapter will illustrate the product based information system and elaborate each component within this framework.

Chapter 3. Product Based Information Sharing (PBIS) Framework

Project information sharing is becoming increasingly important in both public and private organizations (Ramon, 2007). Generally, organizations base their decision to move forward with an information-sharing project on the project's expected benefits such as better services, operational savings, and increased program effectiveness. This chapter presents a product based information sharing (PBIS) framework, which serves in general project planning and lead to properly and effectively benchmarking and recommending product portfolios for project management purposes.

The PBIS framework is to solve the four key challenges highlighted in Chapter 1 in the following ways:

- Provide a guideline to identify useful project best practise information
- Provide a structured way to capture and store useful project information during project management life cycle
- Provide a structured way to present and share best practice information with other projects to improve project performance
- Provide a mechanism to ensure the right products are selected based on products of which attributes are important for customer criteria during the project planning stage, and enable the inclusion of both quantitative and qualitative factors extracted from product based portfolios in the decision process.

This modular framework proposes a clear structure into project planning and management to combat the problems currently being experienced by project managers and tender estimators. It introduced a new product based approach to capture and reuse the project information that tackles the issue of information overloading from a very different perspective and the limitation of activity based approach.

3.1 Overview of PBIS Framework

The PBIS framework is proposed to facilitate the process of capturing, sharing and learning information from previous projects in standardised industries, and present project managers manageable amount of easily-derived information organised to give insight information. To

achieve this goal, PBIS is designed to assist project manager through whole life management of projects based on best practice and experience from previous project portfolios. Project management system developed based on the PBIS framework is able to automatically deliver project plans to match customer requirements in terms of business context, and also provide a mechanism for continuous monitoring of project execution via benchmarking. Within this scope, PBIS can be easily adopted to solve other real world problems through sharing and reusing project historical data in standardised industries such as manufacture, education, medicine, construction and rail industries etc.

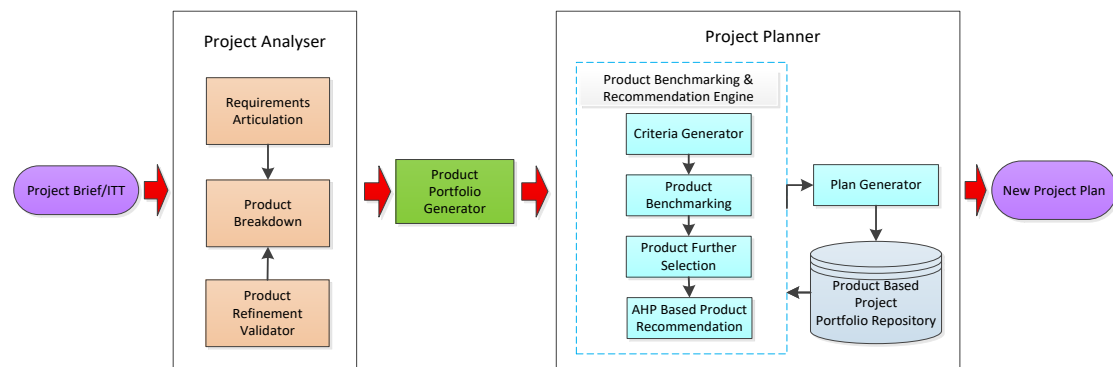


Figure 3-1: Product Based Information Sharing (PBIS) Framework

Figure 3-1 illustrates the proposed project information sharing system framework, which is a methodology that uses the product based approach for portfolio generation and collection, best practice benchmarking and product recommendation. There are two main parts in this framework: Project Analyser and Project Planner, each of them contains several modules to support the functions respectively. The Project Analyser provides analysed and articulated requirement information in both project and product level. This information will be used to cover the needs for project breakdown and product based portfolio management, led to the creation of a novel benchmarking and recommendation methodology in Project Planner part that allows creating a new project plan based on the historical data collected.

In **Figure 3-1**, Project Brief (AXELOS, 2017) or Invitation to Tender (ITT) represents customer's expectations and acceptance criteria for the project as an input. Through Requirements Articulation module, firstly the higher level requirements such as project scope, customer requirements and acceptance criteria in project brief with business case need to be analysed and understood by project team. Then details information such deliverables with detailed requirements, pricing and timeline will be articulated based on input documents. The articulated results then will be further interpreted and used for providing guidance for development of the product breakdown in this thesis. Product Breakdown module consists of

three steps includes PBS, PD and PFD to break project into detailed sub products (deliverables). A regulation will be applied through Product Refinement Validator to validate the product refinement results along with product breakdown technique is applied. As long as PBS is carried out, all simple product objects will be generated as product portfolios through the Portfolio Generator module and then stored into the data repository of product based project portfolio (PBPP).

Next, the Criteria Generator will drive the benchmarking criteria selection and product performance indicator definition through customer requirements articulation and expert's consultancies. After applying the derived benchmarking criteria and product performance indicators to Product Benchmarking, Product Further Selection and AHP Based Product Recommendation modules, the best products that meet the user criteria will be selected if they are available in PBPP repository. The actual delivery information of the selected product such as time, cost, quality, activities, constrains and dependencies will be used as the stepping stones in the new project plan. If there is no existing product to match the user criteria, the knowledge and experience of project manager and experts will be used to create a new product portfolio in PBPP repository. After this done, all selected or new created product portfolios will be integrated together through a Plan Generator to be a new project plan, they will be stored and used as key information of the system for future project planning. At this point, project manager is able to make decision or tuning the details based on the plan according to various situations.

In some of the cases, the new project plan will also be used as the project bidding responses to Invitation to tender (ITT), and very likely it will be changed after project contract is won. The PBIS framework takes this account and allows project manager to amend the plan, such as add or remove products, alter the attribute values of the simple product to meet the project budget and schedule, etc.

In addition, the product based portfolios will be updated along with the progress of the project within the project management life cycle. For example, if a project plan is changed before project starts (of course it must be approved by project board in this case); the original plan information will be saved as an old version in PBPP repository, the new plan will be recorded as new baseline separately for project progress monitoring purpose. After project completed, the actual delivery and maintenance information of each simple product will be recorded for future benchmarking and project management.

3.2 Project Analyser

The Project Analyser part in PBIS contains three modules: Requirements Articulation, Product Breakdown and Product Refinement validator. This part is to analyse the project higher level requirements and articulate the customer quality expectations and project deliverables. The articulated information will be used to assist Project Breakdown process, which will be validated by applying the product refinement rule.

3.2.1 Requirements Articulation

Requirements Articulation module in this framework is responsible to clear the business objectives and identify what is needed to deliver the products, and the defined scope of the project before generating a project plan. Project Brief or Invitation to tender (ITT) is such a document provides the higher level requirements. It is very crucial that project team to understand the project scope of the tackle areas and every individual product (deliverable) in this project must contribute to the end result during this analysis process.

Project Brief or ITT usually consists of following important information, which could be tailored to the requirements (OGC, 2009) and environment of each project:

- Background
- Project Definition
 - Project objectives
 - Project scope and exclusions
 - Outline project deliverables and/or desired outcomes
 - Constraints
 - Interfaces
- Outline Business Case
 - Description of how this project supports business strategy, plans or programmers
 - Reasons why the project is needed
- Project tolerances
- Customer's quality expectations
- Acceptance Criteria

This document captures and defines the deliverables and timeline a vendor will execute against in performance of specified work for a customer. The areas that are addressed by the

Project Brief or ITT cover the scope of the work which describes exact nature of the work to be done, location of work which describes where the work is to be performed, allowable time for projects, deliverables schedule, industry specific standards applied, what objective criteria will be used to state the work is acceptable and special requirements which specifies any special hardware or software.

Project Definition in this document contains a section named “Outline project deliverables and/or desired outcomes” - deliverables are also known as “products”. This section helps define more specifically those things that are within the scope of the project. The required products are listed here that the project will deliver, include both end products and intermediate products on which end products, outcomes or benefits depend. This information will be tailored and used by product breakdown module which will be introduced in next section.

If earlier work has been done, the Project Brief may refer to the historical document(s) containing useful information. This principle is adapted by this thesis in order to speed up the project analysing progress, as many projects in engineering and manufacturing industries always require repeated deliverables and outcomes from the same group of the customers.

3.2.1 Product Breakdown

Most current project planning methods begin a plan by thinking of the activities to be undertaken, and listing these in a hierarchical structure such as WBS which has been discussed in Chapter 2. Although activity based planning comes to us naturally, there are difficulties associated with it. In activity based planning it can be difficult to ensure that all activities are adding value to the project, and are actually necessary to produce the required outcome (Jarvis, 2006; Soora 2013). If there is any ambiguity in what is required from an activity, then there is likely to be a breakdown in understanding at some point, this can be particularly evident if a project has intangible outcomes such as training. Activity based planning is reliant on someone inventing the tasks required on the plan and then it is difficult to ensure that the plan is complete.

The project activities actually depend on what products are required to be produced by the project, so the correct start point for a plan is to list the products (Bentley, 2015). In fact, by jumping straight to the lower level of details of activities, it is likely to miss some vital products and hence vital activities from the plan.

This Product Breakdown module adopts the alternative product based planning technique to break project into products or deliverables which overcomes the limitation mentioned above. The main concept of product based planning technique also has been discussed in Chapter 2. Product based planning gives a clear picture right up front of the outcomes (i.e. the products) of a project. It starts by identifying the final products of a project and any sub-products required to produce these, including management and quality products, then repeatedly refined until all of the requisite products are identified. Each product and sub-product is described in a product description, which includes the skills required to develop them, the quality standards to which they must conform and the measurements that will be taken to guarantee that the products are as required.

The Product Breakdown module in PBIS framework is to ensure that all necessary products are identified and captured. It is a three stage process comprising of:

1.) Product Breakdown Structure (PBS), which is a hierarchical structure with no sequence implied, showing all the projects products including management products. The articulated deliverables information from “Outline project deliverables and/or desired outcomes” section in Project Brief or ITT will be used a reference to generate this structure. It provides project teams with the information they need to understand the requirements of a desired project outcome. Since PBS is visual display of summarised information, it is easy to share across a project team and with planners in an organization, or be transferred to other projects.

PBS encourages “structured thinking” to clarify all necessary work products viewed / grouped visually as an aid to understanding. It avoids overlooking products, and includes all products created, modified or acquired. Also it includes all intermediate products needed to create or support the final product and all external product dependencies. PBS clearly defines the composition or derivation of product’s required and provides an aid to more accurate estimating (effort, resource and timescale).

Users will need to start by identifying the end product that they want to do. For a project manager this is a requirements document or the completed analysis component. Any checks, reviews or supporting documentation that might useful to get to that finished product also need to be included as the identification of the sub products. Supporting documentation can be included even if it’s not in the final deliverable. A set of product refinements rules will be applied to validate the PBS during the process of product breakdown to ensure all sub products to fulfil the conditions of completeness and consistency.

It's also recommended to break the project into products for maximum three levels in order to ensure a clear structure view of the project and avoid confusion.

2.) Product Descriptions (PD) is a clear description of all the products to ensure common understanding. This is the start point for ensuring that they are successfully created. PD provides clarity for everyone on the project team as to what and how is being produced. There should be enough clear guidance that by looking at a product description a team member knows exactly how to go about their work. PD is also a part of information stored in product based portfolio for future benchmarking purpose.

Once users know what they are producing, they need to provide some guidance as to what order it should be produced in. Some tasks may be able to be scheduled in parallel and others will require a precedent. Composing a product flow diagram is a simple diagrammatic way.

3.) Product Flow Diagram (PFD) takes all the products from the PBS and links them in order of production showing dependencies. It shows the transformation from one product or set of products to another. These transformations give users the activities required to produce the products, and provide a sound basis for a detailed and complete project plan and Gantt chart. It also helps in risk assessment associated with dependencies and decide placement of control points such as stage boundaries.

Thus, the whole process is iterative and each step can identify products missed in earlier steps. The process also identifies external products required by, but not produced within the project. An example of applying techniques of PBS and PFD to deliver a project plan is given below. The starting point for a good project planning is a full understanding of the business requirement and scope. The work for planning a new project to be done is to analyse by application of a PBS to delineate the project scope and defining a list of deliverable products to be constructed during the project. The products must be identified before the activities are defined; since the object of the project is to produce deliverables.

At this point, all deliverable products have been identified. The product information such as product name from PBS, descriptions from PD, dependences and pre-requisites from PFD and other useful information will be entered and stored into the data repository of Product Based Project Portfolio through product portfolio generator tool.

Figure 3-2 is an example of project product based structure (PBS) to integrate current IT operations of a corporate into a “Web Based Information Management System (WBIMS)”.

In PRINCE2; the top level of product is known as “project product” or “final product”. For WBIMS project, these cascade into three main categories and represented with diamond shape.

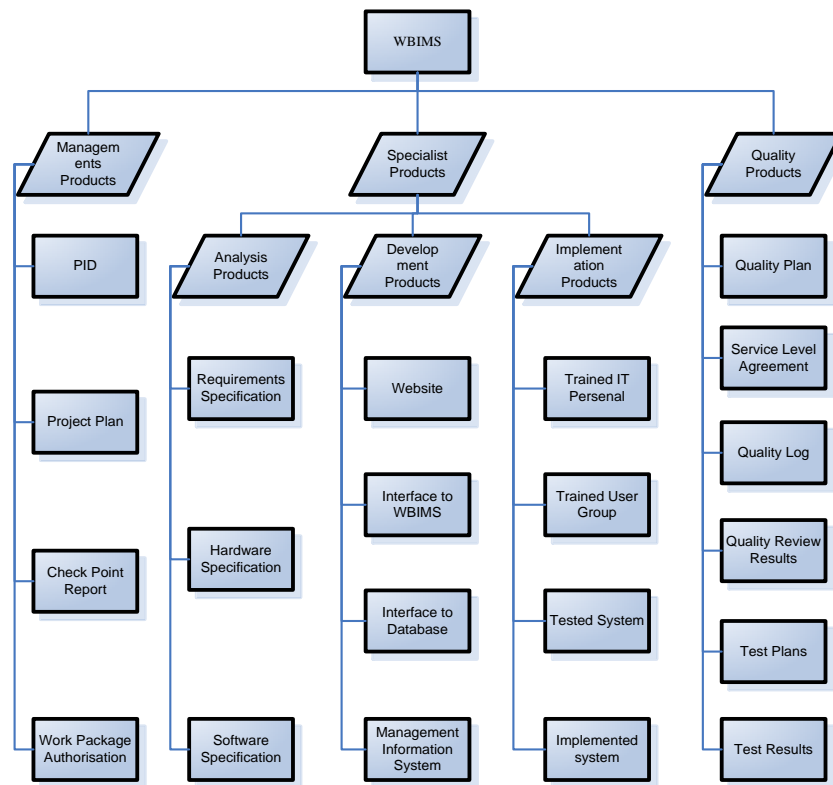


Figure 3-2: A Product Breakdown Structure

Management products presented in the PBS diagram are those products associated with the planning and control of the project. They include Project Initiation Documents (PID), the project plan, checkpoint reports and so on. Quality products are separated from Management products; they are associated with the definition and the control of quality, the quality plan, the product descriptions, the service level agreement, the quality review reports, and the project issues report. Specialist products likewise cascade to those activities the project has been setup and can be broken down into another three sub categories; Analysis Products, Development Products and Implementation Products.

Each sub category similarly includes sub-sub categories below. At the bottom level the individual product is represented with rectangle shape. A project product is broken down further into one or several activities. The estimate of each activity is derived based upon best engineering human judgment from the product estimate and the relative complexity of each activity. Again, the total estimated resource needed for the activities of a product should be equal to the product estimated effort.

Once the PBS is completed, a full list of the products in that project will be generated. Then each product needs to be clearly described and documented properly by project team with introducing Product Descriptions (PD) process. Table 3-1 demonstrates the simple product description for a product “Service Level Agreement” under the group of Quality Products. This document defines the approach to be taken to achieve the required service quality levels during the project.

Table 3-1: Product Description of Service Level Agreement

Product	Service Level Agreement
Purpose	<ul style="list-style-type: none"> This agreement specifies the level of service requires from the selected service provider and provides measurable criteria against which the selected service providers performance will be assessed
Composition	<ul style="list-style-type: none"> Responsibilities of corporate IT department and selected service provider. Mechanisms for monitoring and reporting performance levels. Dispute resolution process. Confidentiality provisions. Conditions for termination of contract.
Format and presentation	<ul style="list-style-type: none"> A4, Word document, printed both sides in black and white Font: Arial, 12pts
Quality criteria	<ul style="list-style-type: none"> Contains all composition items listed above. Not more than 60 pages. Complies with corporate branding standards. No typographical errors.
Quality skills required	<ul style="list-style-type: none"> Proof-reading skills. Director of Compliance Division-Reviewer Director of Information Technology Division Reviewer Administrator
Quality responsibilities	<ul style="list-style-type: none"> Producer Presenter: Director of Facilities Division. Chair: Project Manager

The service level agreement between the corporate and the selected service provider specifies the type and quality of service required. The selected service provider must follow the industry standards for providing outsourced services. The selected service provider also must operate to industry standards for providing outsourced Services. All project service requires from the selected service provider will be subject to a quality review.

After all breakdown products are documented with clear description, it is time to consider the work of creating a PFD. The principle is the products in the relation to each other will be analysed and considered how one product is transformed into another. Each product may consist of one or more activities. Thus, the activities implied in the delivery of each of the products and those required to create or change the planned products need to be identified to give a more comprehensive picture of the plan’s workload.

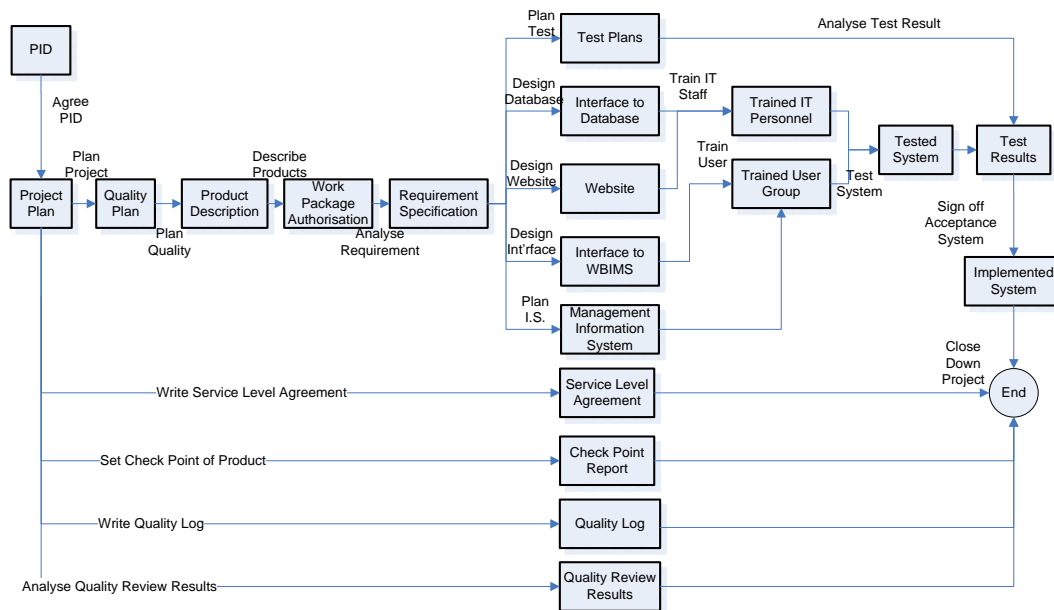


Figure 3-3: A Project Flow Diagram

Figure 3-3 is an illustration of adding the activities and dependencies based on the PBS of WBIMS. As a start, PID is to be agreed firstly in order to create project plan, followed by quality plan, product description, work package authorisation and requirement specification. In terms of the requirements specifications, system test plan, interface to database, website, interface to WBIMS and management information system are implemented in parallel. The database and system trainings will be given to IT personnel and use group respectively after the system implementation is completed. Then the system will be tested based on the test plan, the test results will be used to decide whether the system meets the requirements and acceptance criteria. During the course of system development and testing, several documents such as service level agreement, check point report, quality log and quality review results are generated and signed. After all these products completed, the implemented system is delivered if the system acceptance criteria are met and the project will be closed down.

From the description above, the Product Breakdown module employs product based planning technique to ensure the project is focused on the end result, and all activities in the project plan contribute and add values to the required outcome. The product definitions and their acceptance criteria mean that everyone has the same view of what the products are and therefore the quality of communication improves. The product descriptions also provide a clear measurement of project progress and completion and any external interfaces are identified early on.

Through Product Breakdown module, project manager is encouraged to think through all products that are to be developed before committing time and resource to the creation of a plan. This approach also allows project milestones to be easily identified as these will include the required delivery dates for the project products. Projects with good plans at the outset are more likely to stay on track and achieve the desired outcomes, hence saving time and cost overall. Smaller or simpler projects will have fewer products and so will pass through the process quicker, naturally reducing time spent on the planning process.

To sum up, product based planning is a technique that has been proven to reduce time and cost and improve quality by providing a complete project plan with clearly defined products and realistic milestones. Product Breakdown module in this thesis has adopted this technique to assist project manager to identify deliverable products, capture and store product portfolio product in a structured way.

3.2.3 Rules for Product Refinement and Breakdown

Product based planning technique in PRINCE2 provides a basic guide of doing product refinement, but it does not prescribe a format for the product breakdown structure neither provides a rule for validating the sub-products in practice. The reason of it is that PRINCE2 is a guideline for managing projects, which means it doesn't provide support on the details of the techniques it works with. Also the project management approach could be different from organisation to organisation, and from person to person, the way how to break project into proper sized sub-products could be varied. Therefore, there is a need to set up a regulation to refine product and validate the results when product based planning technique is applied. In this thesis, a set of rules of product refinement was formed to help the user to break project into simple products. This proposed validation rules are inspired by the idea of the Goal refinement model (Jackson, 1995; Zave, 1997; Willem-Paul *et al.*, 1998; Rubio-Loyola *et al.*, 2005; Inoue *et al.*, 2015; Horkoff *et al.*, 2016).

The principle of the validation rules is a set of product $\{P_1, \dots, P_n\}$ refines a product P in a domain Dom if the following conditions hold (Darimont and Lamsweerde, 1996):

1. $P_1, \dots, P_n, Dom \models P$ (completeness)
2. $\bigwedge_{(j \neq i)} P_j, Dom \not\models P$ for each $i \in [1..n]$ (minimality)
3. $P_1, \dots, P_n, Dom \not\models False$ (consistency)

The first condition requires that the satisfaction of the sub-products together with the satisfaction of domain properties in Dom is sufficient for satisfying the parent product. A domain property is a property that naturally holds in the environment (Zave & Jackson 1997). The second condition requires that if a sub-product is left out of the refinement, the remaining sub-products are not sufficient for satisfying the parent product. The third condition requires that the conjunction of the sub-products is logically consistent with the domain theory.

The formal definition of products allows one to verify formally the completeness, minimality and consistency of product refinements. For example, assume a personal computer is the final product P of a project. Its main body (P1), monitor (P2), mouse (P3) and keyboard (P4) are the major components which are sufficient for satisfying the product - personal computer. Without any piece of the components, the product is not a completed personal computer. The main body (P1) of the personal computer can be further refined into body case (P11), power supply (P12), hardware (P13) which consists of CPU, RAM, motherboard, etc., interfaces (P14) and cables (P15), and the monitor (P2) can be further refined into LCD screen (P21), power cable (P22) and support frame (P23). If power source (P12) is missing, the main body (P1) of the personal computer is not a completed product, if the LCD screen (P21) is missing, the monitor (P2) not a completed product either, neither the personal computer (P). Finally, if put LCD screen (P21) into the main body (P1) of the personal computer, or put a CPU (P131) with the monitor (P2), both main body (P1) and monitor (P2) cannot be logically formed as a standard product, apparently the finally product personal computer (P) is not satisfied as a completed product.

Domain properties play a critical role when refining products into sub-products. A domain property is a property that is naturally true about the composite system. Physical laws are typical examples of domain properties. An example of domain property for the meeting scheduling problem is the fact that a participant cannot participate simultaneously in two different meetings. Domain properties are declared as domain invariants attached to products in the product breakdown structure.

The last validation rule for product breakdown is: a project should not be broken down more than three or four levels in order to ensure a clear structure view of the project and avoid confusion. For example, if a product is a computer CPU fan, it's unnecessarily to break it down to smaller sub products such as screws, fan leaves and fan frame, as it is expected to be delivered as an integrated unit.

The refinement rules allow given product refinements to be checked against completeness and consistency. By using the refinement rules, all sub-products broken down will be validated against their parent products and physical laws to ensure they are satisfied with domain properties and the final product is satisfied as a completed product.

Since the project has been broken down to simple products, the next step is to find the best practice among the historic data for project planning. In the case of a number of the same products found from historical data repository, a product benchmarking and recommendation principle will be applied to choose a best suitable product. The activities associated with the chosen product will be regarded as the most suitable practices to deliver the product. To be able to make such selection, a number of indicators need to be predefined to measure the successfulness of the delivery of the product. Among the indicators, different weighting for each indicator may also be applied to reflect the importance of different indicators, the detailed best practice benchmarking and recommendation mechanism will be discussed in detailed in Chapter 4. Finally, all chosen products with most appropriate practice will be integrated to make a new plan which is an output of the PBIS framework, this is also considered as the results of project information is successful transferred and shared.

3.3 Project Planner

The Project Planner part in PBIS contains one data repository and two modules: Product Based Project Portfolio Repository, Product Benchmarking & Recommendation Engine and Plan Generator. The data repository of Product Based Project Portfolio stores all new entered product portfolios together with historical data from previous completed projects. It provides a data source for Product Benchmarking & Recommendation Engine, which will recommend the best products that meet the customer expectations and acceptance criteria. Plan Generator, then will assembly all the best products, generate the new project plan and then store them into the Project Portfolio Repository.

3.3.1 Product Based Project Portfolio Repository

Project portfolio management has promised to take the project management methodology into a new era. It brings the world of practice into tight integration with other business operations (Gutiérrez & Magnusson, 2014). The approaches of using project portfolio for sharing information among projects become more and more important to project organisations (Kopmann, 2017).

The project information stored in activities based portfolio has the same limitation with activity based planning, such as the new project must follow exactly the same activities of the previous project to share that information. To overcome this limitation, Product Based Project Portfolio (PBPP) has been proposed in this thesis. This approach and concept are drawn from product based planning technique and project portfolio management; hence it has the merits of the two concepts. Through PBPP, information can be shared with other projects as long as similar products are found in PBPP. The actual information results of the simple product from previous projects can be used as the basis for planning rather than the project manager's experience. In addition, once the plan has been made and the product completed, information about the product can be stored in PBPP for future use.

In PBIS framework, information associated with each project product is the portfolio of the product. Products with the same properties can be shared among different projects. Similar to project portfolio, the following information of simple products can be collected as product portfolio:

Table 3-2: Product Based Portfolios

Product based project portfolio	
1	Product name and description
2	Duration of completion
3	Resources required (e.g. person allocated with man-day or hours, team size)
4	Cost including labour & material
5	Dependences & pre-requisites
6	Activities undertaken of each product include details of rework
7	Quality assessment criteria
8	Quality Score of Delivery
9	Quality Score of Post Service
10	Special technical requirements
11	Constrains & inheritable risks
12	Lessons learned and comments

The product based portfolio contains the detailed project information at product level, such as product name and description, estimated and actual duration of delivering the product including start date and end date to complete the product, estimated and actual costs to carry out the work including labour, material and management, quality criteria of the delivery, resources required such as person allocated with man-day or hours and team size, associated activities to deliver the product successfully, dependences and pre-requisites of producing this

product, quality assessment requirements and scores, constraints and risks associated with the product, and lessons learned from completing this product and comments received.

If portfolio repository captures and stores the product information properly, project management tools using the product portfolio information would allow organisations to automate the management processes of projects from concept to completion (Brook & Pagnanelli, 2014). The data repository of PBPP in PBIS contains both project and simple product data, which involves not only planning information, but also the actual delivery and maintenance information of those projects. When a new project is planned, the portfolio of previous projects and simple products can be accessed and re-organised into new projects. The number of matching simple products in PBPP might be more than one.

A measurement technique such as benchmarking and product recommendation mechanism are therefore required to judge the successfulness of both projects and products to help determine the most appropriate practice to choose from to make a new plan. As discussed in section 3.2.1, when a project manager plans a new project, firstly is to break the project into simple products by using PBS and PFD, then PBPP will be looked to see whether those products as been done before, as long as the simple products are found as the same, the product benchmarking and recommendation principle can be employed to choose a suitable product. The activities associated with the chosen product will be regarded as the most suitable practices to deliver the product in the new project plan. Of course, project managers sometimes need to estimate the time and cost according to their experience when there is no information found from the system. Actual information collected during the project delivery can be stored into the PBPP system again to cross check the accuracy of the previous planning to improve the calculation method for future references.

Therefore, the proposed PBPP framework has the obvious advantages to allow maximum information and best practice sharing among projects at the product level. It overcomes the limitation of traditional activity based methods when sharing information at the activity level. As a result, it improves information sharing efficiency and delivered real measurement and management of project progress and completion.

3.3.2 Product Benchmarking and Recommendation Engine

In a project environment, the project operational efficiency may be facilitated through the introduction of best practices that are able to optimise the management of organisational

resources (Kawakubo, 2015). However, the detailed practice information from previous projects may be buried in piles of archived documents, which make it increasingly difficult for project organisation to learn from the previous experiences. Although best practise benchmarking has been introduced to improve the information sharing, the amount of sharable information is still limited to generic information. The semantics of vast amount of information contains the best practices of producing certain products (deliverables) are not even collected due to the nature of the traditional activity based project planning approach. Furthermore, even product based portfolio is able to capture, share and reuse the information at product level, sharing best practice through project portfolio is a multi-criteria decision making process, the quality of the criteria are not easy to measure quantitatively.

This thesis proposed a product benchmarking and recommendation mechanism to address above issues, this mechanism works as an engine consisting of four components: criteria generator, product benchmarking, product further selection and AHP based product recommendation. A brief introduction of each stage is as follows, while detailed descriptions are presented in Chapter 4.

1) Criteria generator

All of the customer requirements must be measurable or quantifiable in order to be able to verify that each has been completed. Criteria Generator specifies the criteria requirements of the project being delivered through an analysis. Such analysis takes measures that can be categorised into quantitative and qualitative. The qualitative measures can be used to aid decisions making on the best-fit project products which are selected by using the quantitative criteria. These criteria are related to the project objectives and performance which need to be analysed that leads on to create product portfolios.

2) Product benchmarking

The product benchmarking process adopts a Quartile approach to entails collecting attribute values in ranges corresponding to quartiles and converting it to quartiles for output purposes.

3) Product further selection

The further selection involves an algorithm of Data Envelopment Analysis (DEA) which selects and evaluates a set of alternative products from benchmarking results.

Based on a specific request raised by the customers, a set of performance measures will be derived from the preliminary analysis as input and output. The DEA-analysis is based on linear optimization and the analyses are performed separately to each product.

4) AHP Based Product recommendation

The chosen alternative products will then be further audited in product qualification by adapting a pair-wise comparison algorithm of Analytical Hierarchy Process (AHP) which produces the winning products whose overall performance meet the customer's requirements.

There are three steps that are included in this product recommendation method: (1) structuring the hierarchy of criteria and alternatives for evaluation, and (2) priorities are derived by using the eigenvector method for the criteria and the corresponding requirements. (3) synthesize priorities of the alternatives by criteria into composite measures to arrive at a set of ratings for the alternatives, the overall preference priority for each alternative product is calculated.

3.3.3 Plan Generator

Plan Generator is responsible to assumedly all the product portfolios stored through Product Breakdown module mentioned in section 3.2.1, or produced through the Product Benchmarking and Recommendation Engine, and then generate a new project plan. Project manager is able to use Plan Generator to generate a project plan automatically without any modification or after manual tuning of the products (such as add or remove products from the products list). In this case, as long as the products together with their associated activities are selected from the desirable project(s) and submitted for assembling; the product portfolios with the details (e.g. product name, activity name, dependencies and feedback) will be copied cross to the new project. The new project plan will be saved into the Product Based Project Portfolio Repository as a baseline, which will be used a project progress monitoring purpose.

3.6 Summary

This chapter has discussed various key issues that pertain to proposed framework of information sharing in project management as well as formed product refinement rules and selected product benchmarking and recommendation method, which is expected to act as a guide toward developments of detailed benchmarking process in practice.

With this structure, the product based information sharing framework provides a better guidance to the project manager as it can help in shaping its plan and decomposing global project effort into product efforts, ensuring the project will meet its goals in terms of the acceptance criteria. It is specifically designed for managing projects following a well-defined process - PRINCE2, typical in engineering and manufacturing industries (e.g. mechanical, electrical, construction, software and civil). This framework takes advantages of this fact by gathering statistics which provide assistance during project management.

This chapter firstly introduced the Project Analyser provides analysed and articulated requirement information in both project and product level. Based on the information obtained from Requirements Articulation module, Product Breakdown module is responsible to break the whole project into products and sub products by adapting the product based planning technique. It consists of following steps: product breakdown structure is a hierarchical structure of products that the project will deliver, it can be thought of as the project “shopping list.” It decomposes an end project product into its constituent parts in the form of a hierarchical structure. Product description provides a clear guidance for team members knowing exactly how to go about their work. Product flow diagram takes all the products from the product breakdown structure and links together.

This Project Analyser with its supporting modules is very important particularly significant with engineering and manufacturing projects. Firstly, it is possible to identify all the deliverables that are required which leads to a better understanding about the work needed to be done. Also project team members are able to break down the complexity to the simplest level of understanding by using product based planning. The simple products will be used as the basic units to carry project practise information which can be shared with other projects as long as similar products are found in product based portfolio. The actual information results of the simple product from previous projects can be used as the basis for planning rather than the project manager’s experience.

The Project Planner has also occupied a considerable part of the work. The data repository of Product Based Project Portfolio stores all new entered product portfolios together with historical data from previous completed projects. It provides a data source for Product Benchmarking & Recommendation Engine, which will recommend the best products that meet the customer expectations and acceptance criteria. Plan Generator is responsible to assembly all the best products and generate the new project plan. The Product Benchmarking & Recommendation Engine is using the creation of a novel benchmarking and

recommendation mechanism that has four components: Criteria Generator module specifies the criteria requirements of the final project being delivered through an analysis. Product benchmarking module generates a range of benchmarked results, DEA enables a Product Further Selection module which assesses the product's portfolio and identifies the optimum alternatives towards the customer's request. In AHP based Product Recommendation module, AHP algorithm is adapted to evaluate an optimisation of the alternative products and determines a ranking for them via qualitative outputs. Compared to the traditional, mainly active based information sharing approach which only considers quantitative variables, the utilization of this approach enables the inclusion of both quantitative and qualitative factors extracted from product based portfolios in the decision process. This is quite useful for the projects where some of their performance measures are qualitative in engineering and manufacturing industries. As long as the recommended products together with their associated activities are selected from the desirable project(s) and submitted for assembling, the portfolios will be copied cross to the new project. The effort (e.g. time and cost) of each activity will be calculated based on the customised benchmarking criteria and recommendation algorithms.

In summary, the main achievements of the PBIS framework are: it overcomes the imitation of traditional activity based methods when sharing information at the activity level. Instead, it allows maximum information and best practice sharing among projects at the product level. It liberates the project manager from the responsibilities such as business case, business strategies to concentrate on the project deliveries. It also provides the freedom for the technical expertise to choose the best practices on the delivery of the products with little or no interferences for the senior managers. PBIS framework provides a management structure to allow the senior management level focuses on why the project is needed, the middle level of management concentrates on what are the products to produce and the lower level of management focuses on how the products are made. PBIS framework is the attempt to automate project planning processes with an information system based on previous project delivery and best practices. It also brings the possibility of providing global access for projects to share product portfolio in standardised industries.

Next chapter will introduce integrated benchmarking and recommendation mechanism in details.

Chapter 4. Product Benchmarking and Recommendation Mechanism

A good project information sharing and management system should be able to deal with the problem of information overload by benchmarking best practise information fragment out of a large amount of existing project information according to customer criteria (Hamilton, 2000).

Benchmarking in project management is to efficiently obtain project performance data and related best practices in order to improve project management process and information sharing. This method has been widely used by project managers to fulfil the increasing demands of planning and controlling in the projects. Historical data may be used to support extension of time claims and dispute resolution as well as in future projects of a similar nature. As benchmarking can be employed to provide a systematic approach through comparing and analysing the values from varying resources in the project, through benchmarking and utilising best project practice, project knowledge and information can be shared and transferred for enterprises to persist in contract competition and project planning.

Although project management today is seen as a systematic process (Goh, 2005), the lack of comparable objectivity has been well recognised as the major issue within project management evaluation exercises. As discussed in Chapter 2, if the project processes or activities are taken by project managers differently, then the evaluation of the managing of differing processes will be flawed, the information cannot be easily benchmarked and reused for the new project unless the new project will take exact same activities or processes as the previous one. Furthermore, most project benchmarking practices are made explicit in terms of persistent data from historical operational processes or activities, but underlying influencing factors, lessons learned and qualitative information remains implicit. The risk of such practice is the cost estimation will not take account of other factors such as different environment, technology advances and different customer quality requirements. Many engineering companies have previously been financially penalised by such poor benchmarking techniques. In addition, benchmarking often requires excessive time and cost of gathering and analysing performance data, it can consume scarce resources (Cadle and Yeates, 2014). Therefore, benchmarking the management of project with right project information and right criteria can be time consuming and expensive, especially during the project planning stage.

As a promise of improving information sharing, a novel product benchmarking and product recommendation method is developed in PBIS to deliver reliable results that can support decision making and enhance performance of project planning and monitoring. The recommendation approach proposed in this thesis is to improve multi criteria decision making process and quality among the amount of preselected products after benchmarking process. The new method integrated with the strengths of Quartile, Data Envelopment Analysis (DEA) and Analytic Hierarchy Process (AHP) to ensure the right products are selected based on products of which attributes are important for customer criteria during the project planning stage.

Section 4.1 provides an overview of the mechanism, Section 4.2 focuses the criteria generation through product analysis; section 4.3 discusses the Quartile approach for product benchmarking; section 4.4 presents the processes of product further selection by using DEA, and leads to the final section 4.5, the stage of AHP based product recommendation.

4.1 Overview

Figure 4-1 presents the mechanism with four stage components: criteria generator, product benchmarking, product further selection and AHP based product recommendation.

Before initialising Criteria Generator, project expert team needs to use their knowledge to define the project performance criteria through the interpretation of the important project documents such as Project Brief or ITT. The Criteria Generator then specifies the criteria requirements of the project being delivered through such analysis which takes measures that can be categorised into quantitative and qualitative. These criteria are related to the project objectives and performance which need to be analysed that leads on to create product portfolios. Next, Product Benchmarking stage adopts a Quartile approach to entails collecting attribute values in ranges corresponding to quartiles and converting it to quartiles for output purposes. The benchmarking criteria and prior key performance indicator (e.g. Time and Cost) with the quartile values need to be specified by project manager in this stage. Product based project portfolio repository provides the data source for benchmarking at this stage. The benchmarking results will be through a Product Further Selection stage, which involves an algorithm of Data Envelopment Analysis (DEA) to select and evaluate a set of alternative products from the benchmarking results. In this stage, a set of performance measures need to be derived as input and output through previous analysis in last stage by project expert team. Relative efficiencies will be evaluated to determine the satisfied units from the benchmarking

results. In order to further be decided as a winning unit for the request, AHP is adapted at the product recommendation stage. Firstly, a hierarchy for the decision needs to be built; next the relative priorities (weights) for the criteria and sub criteria need to be derived. Then each of the criteria and sub criteria needs to be evaluated through pairwise comparison to check whether they are consistent. If they are not consistent, project expert team needs to redefine the relative priorities for the criteria until they pass the consistency check. At last the overall weighted average rating and final priority needs to be calculated and totalled for each alternative, this process facilitates an optimisation of the competitive products and determines then a ranking for the winning product(s). The best suitable products will be saved to product based project portfolio repository as new product portfolio.

The rest sections of this chapter will go through each stage components in detail.

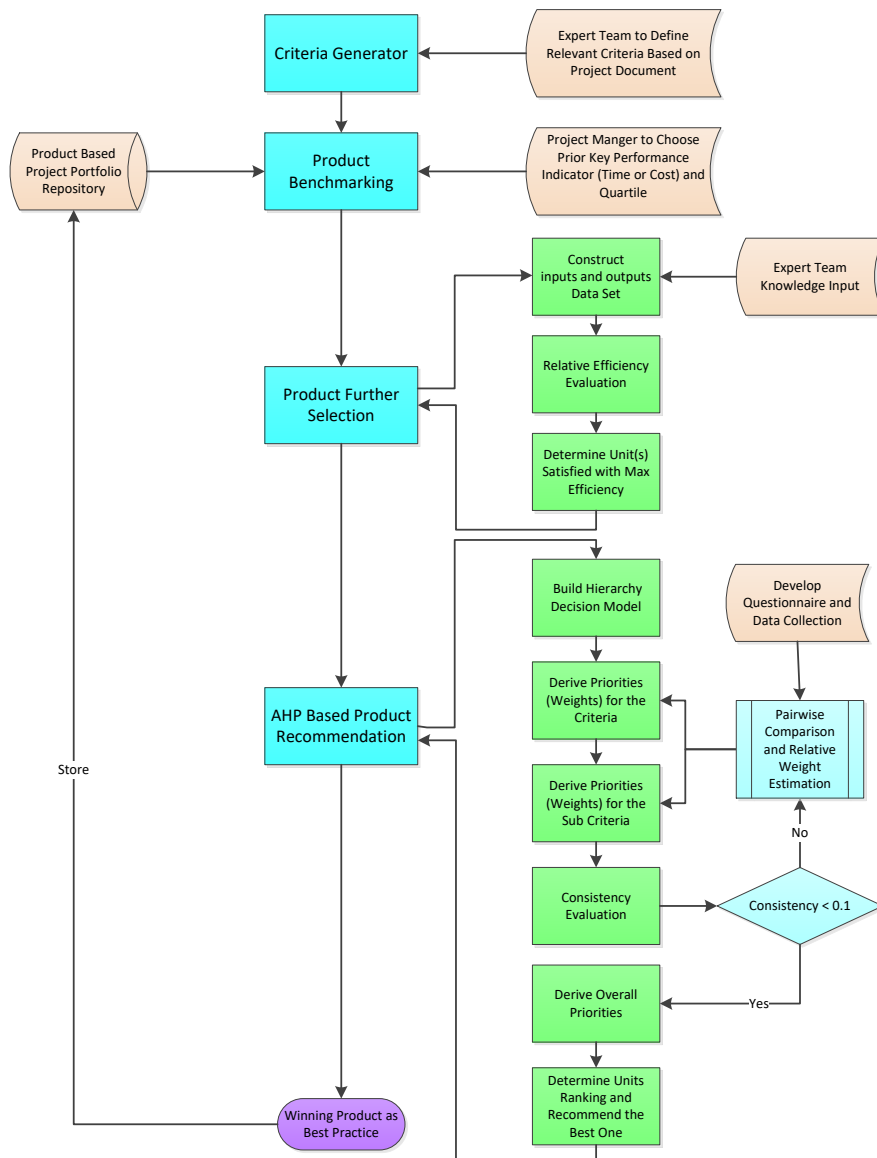


Figure 4-1: Product Benchmarking and Recommendation Mechanism

The following pseudo code presents the logic flow of the mechanism:

input: benchmarking criteria through customer requirements articulations

output: the most suitable product with best practise

Connect to product portfolio repository and get a list of completed product portfolios

if (the number of name matched product portfolios > 0)

then {

if (the number of name matched product portfolios ≥ 2)

apply [*Quartile based product benchmarking*] process defined in Section 4.3

generate a list of benchmarked product portfolios

if (the number of benchmarked product portfolios ≥ 2)

then {

apply [*Product Further Selection through DEA*] process defined in Section 4.4

generate alternative products

if (the number of alternative products ≥ 2)

then {

apply [*AHP based product Recommendation*] process defined in Section 4.5

return the most suitable product

}

else {

return the only product as the most suitable product

}

}

else {

return the only product as the most suitable product

}

}

else {

return the only product as the most suitable product

}

}

else {

create a new product portfolio

}

4.2 Criteria Generator

Criteria Generator specifies the requirements of the final project being delivered through an analysis. Concerning this process, decision makers (DM) face a multi-criteria problem that comprises qualitative (intangible) and quantitative (tangible) factors, such analysis takes measures that can be categorised into quantitative and qualitative towards the project goals.

Almost all organisations want their projects to be on time, meet quality objectives, and not cost more than the allocated budget. Thus the primary objective of project management is to meet or exceed the customer expectations in cost, scheduled time and quality. During this research, the project performance measurement issues have been consulted and discussed with experienced project managers in standardised industries. Also prospective customers have been met to reach a consensus on which major criteria are important for given products in this domain. Through many meetings and discussions, a set of basic performance benchmarking criteria was summarised and identified which are illustrated in **Table 4-1**.

The criteria *Cost* can be measured quantitatively for monetary value to labour, material and team size, the criteria *Scheduled Time* can be measured quantitatively for the duration of completing a product, and the criteria *Quality* is categorised into quantitative and qualitative measures, quality management intention and delivery standard are treated as the qualitative measures, on-time delivery and post service are treated as quantitative measures.

Table 4-1: Performance benchmarking criteria for product selection

Criteria	Type	Description
Cost	Quantitative	Monetary value to labour, material and overhead
Time	Quantitative	Duration of completing a product
Quality	Qualitative	<ul style="list-style-type: none"> • Quality management intention • Delivery standard and post service
	Quantitative	<ul style="list-style-type: none"> • On-time delivery • Meet quality standards • Response to alert • Response to maintenance request etc.

The qualitative measures can be used to aid decisions making on the best-fit project products which are selected by using the quantitative criteria. These criteria are related to the project objectives and performance which are analysed that leads on to create product portfolios. Such information enables to conduct benchmarking to identify best practise products during project planning. This type of analysis in the product based benchmarking process is essential, because the outcomes of the analysis constitute suitable selection criteria for a product pre-selection to meet customer requests. The benchmarking performance criteria in **Table 4-1** are used as a standard for the later stages of the method. The criteria will be measured and

aggregated by employing efficiency ranking algorithm DEA and multi criterion algorithm AHP.

4.3 Product Benchmarking

In a project environment, the project operational efficiency may be facilitated through the introduction of best practices that are able to optimise the management of organisational resources. Effectiveness of benchmarking depends on the use of tools for collecting and analysing information and deriving subsequent improvement of project knowledge sharing.

To be able to make such selection, a number of indicators need to be predefined to measure the successfulness of the delivery of the product. Among the indicators, different weighting for each indicator may also be applied to reflect the importance of different indicators. As each project is different and fits differently onto the strategic map of an organization as well as suiting customer requirements, the key performance indicators (KPIs) to be measured can be changed from project to project. There is agreement on a few principles for selecting KPIs for project management, which are related to time, budget and scope (Kerzner, 2017). In this thesis the criteria of time and cost have been chosen as the major benchmarking indicators due to the factor that time and cost are the two first high priorities to be considered during the ITT and project planning stage. In most cases of engineering and manufacturing industries, benchmarking is among a large amount of data the average isn't giving the expected results, project users would like to see a range of benchmarked results. Quartiles benchmarking approach is able to provide quantitative information that assists project managers to review product portfolios in a fast and efficient manner.

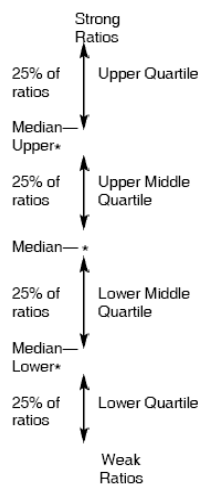


Figure 4-2: Quartile Points

In Quartile approach, each ratio has three points, or “cut-off values,” that divide an array of values into four equal-sized groups called quartiles, as shown in **Figure 4-2**. The quartiles include the upper quartile, upper-middle quartile, lower-middle quartile, and the lower quartile. The upper quartile is the cut-off value where one-quarter of the array of ratios falls between it and the strongest ratio, it cuts off highest 25% of data = 75th percentile. The median is the midpoint - that is, the middle cut-off value where half of the array falls above it and half below it, it cuts data set in half equals 50th percentile. The lower quartile is the point where one-quarter of the array falls between it and the weakest ratio; it cuts off lowest 25% of data equals 25th percentile.

Table 4-2: Quartile Levels

User Requirement			
Time (Prior)		Cost	
Quartile	Criteria	Quartile	Criteria
Maximum	1	Maximum	1
Upper Quartile	0.75	Upper Quartile	0.75
Medium	0.5	Medium	0.5
Lower Quartile	0.25	Lower Quartile	0.25
Minimum	0	Minimum	0

The formula below is to locate the position of the observation at a given percentile, y , with n data points sorted in ascending order is:

$$L_y = n \cdot \frac{y}{100}$$

- Case 1: If L is a whole number, then the value will be found halfway between positions L and $L+1$.
- Case 2: If L is a decimal, round up to the nearest whole number. (for example, $L = 1.2$ becomes 1).

Here is an example to find the median, lower quartile, upper quartile and interquartile range of the following data set of scores:

33 20 23 20 23 24 9 23 27

The solution is to arrange the values in ascending order of magnitude:

9 20 20 23 23 23 24 27 33

There are 9 values in the data set.

$$n = 9$$

$$\begin{aligned}
\text{Median} &= [(n+1)/2]^{\text{th}} \text{ value} \\
&= [(9+1)/2]^{\text{th}} \text{ value} \\
&= 5^{\text{th}} \text{ value} \\
&= 23
\end{aligned}$$

$$\begin{aligned}
\text{Lower quartile} &= [(n+1)/4]^{\text{th}} \text{ value} \\
&= [(9+1)/4]^{\text{th}} \text{ value} \\
&= 2.5^{\text{th}} \text{ value} \\
&= (20 + 20)/2 \quad (\text{Average of the 2}^{\text{nd}} \text{ and 3}^{\text{rd}} \text{ values}) \\
&= 20
\end{aligned}$$

$$\begin{aligned}
\text{Upper quartile} &= [(n+1)3/4]^{\text{th}} \text{ value} \\
&= [(9+1)3/4]^{\text{th}} \text{ value} \\
&= 7.5^{\text{th}} \text{ value} \\
&= (24 + 27)/2 \quad (\text{Average of the 7}^{\text{th}} \text{ and 8}^{\text{th}} \text{ values}) \\
&= 25.5
\end{aligned}$$

$$\begin{aligned}
\text{Interquartile range} &= \text{Upper quartile} - \text{Lower quartile} \\
&= 25.5 - 20 \\
&= 5.5
\end{aligned}$$

Therefore, this means the middle 50% of the data values range from 20 to 25.5.

Quartile approach shows the spread of the most popular for non-numerical data. This concept refers to the subset of all data values in each of those parts. For example, if company executives want to know which project's performance is in the Upper quartile range of the same industry, it means that requested project products are the values in the Upper quartile subset (i.e. the top 25% of all products in the database). If company executives want to know which project's performance is in the Lower quartile range, it means that requested project products are the values in the lower quartile subset (i.e. the bottom 25% of all products in the database). It's especially useful to generate various summary reports on project performance and benchmarking results. In this thesis, Quartile approach provides a benchmarking process to find and shortlist a reasonable range of best practice products from massive stored product portfolios.

For example, there are 25 records related "Cooling Blower" product found in historic product portfolio repository. In terms of the user requirements, the criteria expectation of project completion *Time* and project completion *Cost* are both set as Upper Quartile (see **Table 4-2**), which means all the sub-products in this project will be benchmarked by following steps:

- 1) the top 25% products of all products in data repository that have a fairly good completion *Time* will be selected firstly,
- 2) these selected products will be put into the second round selection to meet the lower prior criteria - the top 25% of the completed products have a fairly good *Cost* ranking among the selected products from step one.

Products in the range that meet both the criteria on *Time* and *Cost* will be regarded as the best practice benchmarking results for further ranking and qualification. **Table 4-3** shows the selected product portfolio of this product in history with serial numbers attached and sorted list order by completed *Time*.

Table 4-3: Example of Historic Data in Time Order

Cooling Blower						
Historic Data			Processed Data by Time Order			
Serial No.	Time (day)	Cost (£)	Order No.	Serial No.	Time (day)	Cost (£)
1	5	495	1	8	6.5	705
2	3	650	2	15	6	620
3	2.5	785	3	18	6	610
4	4	430	4	7	6	600
5	4	450	5	17	5.5	605
6	3.5	715	6	9	5.5	550
7	6	600	7	22	5	505
8	6.5	705	8	14	5	500
9	5.5	550	9	1	5	495
10	2.5	805	10	21	4.5	520
11	3.5	650	11	20	4.5	515
12	3.5	660	12	5	4	450
13	4	405	13	4	4	430
14	5	500	14	13	4	405
15	6	620	15	19	3.5	760
16	3	785	16	6	3.5	715
17	5.5	605	17	12	3.5	660
18	6	610	18	11	3.5	650
19	3.5	760	19	16	3	785
20	4.5	515	20	2	3	650
21	4.5	520	21	24	3	485
22	5	505	22	23	3	450
23	3	450	23	10	2.5	805
24	3	485	24	25	2.5	790
25	2.5	790	25	3	2.5	785

Based on the data table above, *criteria_level* = 5 (1, 0.75, 0.5, 0.25, 0), *counter* = 25 (product portfolio records)

$$\text{time_criteria} = \text{project_time_criteria} \times 4 = 0.75 \times 4 = 3$$

$$\text{cost_criteria} = \text{project_cost_criteria} \times 4 = 0.75 \times 4 = 3$$

$$\text{array_position_actual} = \text{project_time_criteria} \times (\text{counter}) = 3 \times 25/4 = \mathbf{18.75}$$

$$\text{array_position} = \text{Int}(\text{array_position_actual}) = \text{Int}(18.75) = \mathbf{18}$$

The *Int* function returns the integer part of a decimal number by rounding down to the integer.

In this case, array_position (18) equals the 19th record in the order list is closer to the actual benchmarked point (18) in the array list, relevant products from 19th to 25th in the array which are the top 25% of all products will be chosen based on the *Time* criteria expectation.

Next step is to benchmark the products based on the *Cost* criteria from the top 25% of all products (six records) selected above. **Table 4-4** shows the sorted list order by spent *Cost*.

Table 4-4: Example of Historic Data in Cost Order

Cooling Blower						
Historic Data			Processed Data by Cost Order			
Serial No.	Time (day)	Cost (£)	Order No.	Serial No.	Cost (£)	Time (day)
1	3	785	1	5	805	2.5
2	3	650	2	6	790	2.5
3	3	485	3	1	785	3
4	3	450	4	7	785	2.5
5	2.5	805	5	2	650	3
6	2.5	790	6	3	485	3
7	2.5	785	7	4	450	3

$$\text{Based on the table above, array_position_actual} = \text{project_cost_criteria} \times (\text{counter})$$

$$= 3 \times 7/4 = \mathbf{5.25}$$

$$\text{array_position} = \text{Int}(\text{array_position_actual}) = \text{Int}(5.25) = \mathbf{5}$$

In this case, array_position (5) equals the 6th record in the order list is closer to the actual benchmarked point (5.25) in the array list, relevant products 6th (Spent Cost £485 and Delivery Time 3 days) and 7th (Spent Cost £450 and Delivery Time 3 days) in the array will be chosen. There are only two products are selected as best practice through the quartile benchmarking approach in this example, In practice, the benchmarked results is much larger. Further product selection steps are needed to pick the best qualified product from the benchmarked results for building a new project plan.

4.4 Products Further Selection

The most feasible products are generated by using Quartile approach has been discussed in last section to filter all the project products' portfolios in the data repository and shortlist the possible products from several hundred even thousands potential products. In this stage, benchmarked product shortlist will be further selected which involves defining the alternative products by using DEA.

DEA is a methodology based on a linear programming (LP) model for evaluating relative efficiencies of decision making units (DMUs) with common inputs and outputs. It calculates an overall efficiency for the DMU in which its efficiencies are aggregated into a single value. The obtained efficiency is not absolute as it is measured relative to a set of comparable DMUs. In this thesis, a DMU represents an actual project product may be competitively measured against other project products on their overall performance based on a set of product performance criteria (see **Table 4-1**). Each pre-selection may focus on priority hence product performance efficiency can be measured by a weighted sum of outputs to a weighted sum of inputs. The equation (1) represents the pre-selection model.

$$Relative\ Efficiency\ (h) = \frac{\sum_{r} \text{weighted outputs}}{\sum_{i} \text{weighted inputs}} = \frac{\sum_{r} u_r y_{rj}}{\sum_{i} v_i x_{ij}} \quad (1)$$

where

$u_r, v_i \geq 0$, and $j = 1, 2, \dots, n$

i = number of inputs

r = number of outputs

j = number of DMU

x_{ij} = the amount of input i of DMU $_j$

y_{rj} = the amount of output r of DMU $_j$

v_i = the weight input i

u_r = the weight for output r

The v_i and u_r are variables of the problem and are constrained to be greater than or equal to some small positive quantity (Kao *et al.*, 2014) in order to avoid any input or output being totally ignored in determining the efficiency.

The relative efficiency from DEA is normally decided by either maximizing outputs h_o or minimizing inputs $\min_{g_o, \lambda}$. In this thesis, maximizing outputs h_o will be considered as it is defined in the equation (2).

$$\begin{aligned}
\text{Max } h_0 = \sum_r u_r y_{rj_0} \quad & | \quad \sum_i v_i x_{ij_0} = 1 \\
\sum_r u_r y_{rj} - \sum_i v_i x_{ij} \leq 0, \quad & j = 1, 2, \dots, n \quad u_r, v_i \geq 0
\end{aligned}
\tag{2}$$

DEA is capable of discovering those DMUs which hold a range of value of h_0 based on the selection criteria. DMU is assigned the highest possible efficiency score (h_0) that constraints allow from the available data by choosing the optimal weights for the outputs and inputs. If a DMU receives the maximal value $h_0 = 1$, then it is efficient, but if $h_0 < 1$, it is inefficient, since with its optimal weights, another DMU receives the maximal efficiency.

If the initial computation indicates that the current weights are not feasible - all DMUs result in efficiencies which are less than one ($h_0 < 1$), then the weights need to be computed based on the constraints of $\text{Max } h_0 = \sum_r u_r y_{rj_0} \quad | \quad \sum_i v_i x_{ij_0} = 1$ for each focal DMU.

The rest of the section will demonstrate how to use DEA to select alternative products. For example, five products (shown in **Table 4-5**) are pulled out from more than eighty completed products named “AM4-5KW” in historical projects after applying Quartile benchmarking. Based on a specific request raised by the customers, a set of performance measures will be derived from the analysis in Criteria Generator module as input (time, material cost, labour cost and team size) and output (the quality of product delivery, the quality of post service). The data in the **Table 4-5** below represents these 5 DMUs (P1, P2, P3, P4 and P5).

Table 4-5: The raw data of the benchmarked products

DMUs	Time (day)	Material Cost (£)	Labour Cost (£)	Team Size (Man)	Delivery Quality (%)	Post Service (%)
	Input			Output		
P1	4.5	168	450	5	100	80
P2	4	168	500	4.5	90	90
P3	5	200	450	4	80	100
P4	4	134	300	3	80	90
P5	4	134	400	4	90	80

After normalisation by using (3), the data are illustrated as **Table 4-6**:

$$\text{Normalised data, } x_{ij}^* \text{ (or } y_{rj}^*) = \frac{x_{ij}}{\max(x_i)} \left(\text{or } \frac{y_{rj}}{\max(y_j)} \right)
\tag{3}$$

The weights need to be decided are in columns “Time” to “Post Service” (all weights set equal to 1.00 initially). The weighted output for each DMU is given in column “Weighted Output” and the weighted input in column “Weighted Input”. The efficiency for each DMU (given the current weights) is calculated in column “Efficiency (h_0)”. The initial computation

indicates that the current weights are not feasible - all the 5 DMUs result in efficiencies which are less than one ($h_0 < 1$). The weights then need to be computed based on the constraints of

$$\text{Max } h_0 = \sum_r u_r y_{rj_0} \quad | \quad \sum_i v_i x_{ij_0} = 1 \text{ for each focal DMU - P1, P2, P3, P4 and P5 respectively.}$$

Table 4-6: The pre-selection results based on the equal weights

DMUs	Time	Material Cost	Labour Cost	Team Size	Delivery Quality	Post Service	Weighted Input	Weighted Output	Efficiency (h_0)
	Input				Output				
P1	0.9	0.83	0.9	1	1	0.8	3.63	1.80	0.50
P2	0.8	0.83	1	0.9	0.9	0.9	3.53	1.80	0.51
P3	1	1	0.9	0.8	0.8	1	3.70	1.80	0.49
P4	0.8	0.67	0.6	0.6	0.8	0.9	2.67	1.70	0.64
P5	0.8	0.67	0.8	0.8	0.9	0.8	3.07	1.70	0.55
Weight	1.00	1.00	1.00	1.00	1.00	1.00			

To calculate the efficiency of unit P1, the objective function is defined as:

$$\text{Maximize efficiency } h_0 = (u_1 \times 1 + u_2 \times 0.8) / (v_1 \times 0.90 + v_2 \times 0.83 + v_3 \times 0.9 + v_4 \times 1)$$

which is subject to all efficiency of other units (efficiency h_0 cannot be larger than 1):

subject to the efficiency of unit P2:

$$(u_1 \times 0.9 + u_2 \times 0.9) / (v_1 \times 0.8 + v_2 \times 0.83 + v_3 \times 1 + v_4 \times 0.9) \leq 1$$

subject to the efficiency of unit P3:

$$(u_1 \times 0.8 + u_2 \times 1) / (v_1 \times 1 + v_2 \times 1 + v_3 \times 0.9 + v_4 \times 0.8) \leq 1$$

subject to the efficiency of unit P4:

$$(u_1 \times 0.8 + u_2 \times 0.9) / (v_1 \times 0.8 + v_2 \times 0.67 + v_3 \times 0.6 + v_4 \times 0.6) \leq 1$$

subject to the efficiency of unit P5:

$$(u_1 \times 0.9 + u_2 \times 0.8) / (v_1 \times 0.8 + v_2 \times 0.67 + v_3 \times 0.8 + v_4 \times 0.9) \leq 1$$

and non-negativity and all v_i and $u_r \geq 0$.

After equation solving, input weights are changed to $v_1 = 0$, $v_2 = 0$, $v_3 = 0.285714$, $v_4 = 0.742857$, output weights are changed to $u_1 = 0.771429$, $u_2 = 0.2857$ and the Maximize efficiency $h_0 = 1$.

Table 4-7: The results from considering P1 as a focal DMU

DMUs	Time	Material Cost	Labour Cost	Team Size	Delivery Quality	Post Service	Weighted Input	Weighted Output	Efficiency (h_0)
	Input				Output				
P1	0.9	0.83	0.9	1	1	0.8	1.00	1.00	1.00
P2	0.8	0.83	1	0.9	0.9	0.9	0.95	0.69	0.73
P3	1	1	0.9	0.8	0.8	1	0.85	0.62	0.72
P4	0.8	0.67	0.6	0.6	0.8	0.9	0.62	0.62	1.00
P5	0.8	0.67	0.8	0.8	0.9	0.8	0.82	0.69	0.84
Weight	0	0	0.285714	0.742857	0.771429	0.2857			

Table 4-7 above shows the result from considering P1 as a focal DMU which produced satisfactory result of $h_0 = 1$.

The detailed calculation and results from considering P2, P3, P4 and P5 as focal DMUs which produced satisfactory result of $h_0 = 1$, can be found from **Appendix A**.

The solution to the above model gives a value h_0 , the efficiency of the calculated DMU, and the weights leading to that efficiency. If $h_0 = 1$ then calculated DMU is efficient relative to the others but if h_0 turns out to be less than 1 then some other DMU(s) is more efficient than calculated DMU, even when the weights are chosen to maximise calculated DMU's efficiency.

Table 4-8 below shows the gathering results from considering each DMU respectively as a focal DMU which have been highlighted on **Table 4-7**, **Table A-1**, **Table A-2**, **Table A-3** and **Table A-4** in **Appendix A**. DMUs P1, P2 and P5 are satisfied the maximum efficiency $h_0 = 1$. This implies that these three DMUs are competitive products meet the customer's request and could be potentially selected as the winning products.

Table 4-8: The consolidated DEA results for the DMUs

DMUs	Time	Material Cost	Labour Cost	Team Size	Delivery Quality	Post Service	Weighted Input	Weighted Output	Efficiency (h_0)
	Input				Output				
P1	0.9	0.83	0.9	1	1	0.8	1.00	1.00	1.00
P2	0.8	0.83	1	0.9	0.9	0.9	1.00	1.00	1.00
P3	1	1	0.9	0.8	0.8	1	1.00	0.78	0.78
P4	0.8	0.67	0.6	0.6	0.8	0.9	1.00	0.90	0.90
P5	0.8	0.67	0.8	0.8	0.9	0.8	1.00	1.00	1.00

As there are three DMUs which satisfy maximum efficiency $h_0 = 1$ found, they need to further be decided as a winning DMU for the request. AHP based product recommendation, therefore, is used to assist for such decision making and quantify qualitative data. If all five DMUs are inefficient units which means their efficiency scores are less than maximum efficiency $h_0 = 1$ but more than 0, they will be further decided through AHP based product recommendation stage to select a winning DMU.

4.5 AHP Based Product Recommendation

In this final stage, the chosen alternative products need to be further audited in product qualification and recommended to project managers in order to produce the winning product that overall performance meets the customer's requirements.

Quality is considered as a measure of client satisfaction by many literatures (Orel & Kara, 2014; Zareiforush et al., 2015; Han & Hyun, 2015; Water & Benjamin, 2016). As the quality is one of the major project attributes together with time and cost, measure product quality is a subjective measurement which should be collected as quantitative data. A proper method for assessing quality in project management enables project managers to elucidate and structure the needs and expectations of the client. The most common way to measure quality is to decompose the overall quality objective into its main attributes and criteria and relating these to project deliverables. In this case, overall client satisfaction can be decomposed into a hierarchical structure of quality criteria. This is performed through a top-down process whereby the more general objectives are decomposed into lower-level objectives in greater detail. This quality measurement approach is adapted by this thesis: it firstly requires the identification of the multi quality attributes that are relevant for the project deliverables. From among the attributes identified, those attributes that are most relevant are selected.

Therefore, this research developed a product recommendation mechanism to adapt the multi-criterion algorithm Analytic Hierarchy Process (AHP) which is based on the weighted summary to evaluate the overall quality of each product. An evaluation score is then calculated for each product by multiplying the scaled value given to the alternative of that attribute with the weights of relative importance directly assigned by decision maker followed by summing of the products for all criteria.

There are three steps that are included in the AHP based product recommendation stage:

- 1) Construct of criteria hierarchy for the decision making,
- 2) Pairwise comparison of the criteria and sub criteria,
- 3) Criteria weight aggregation and priority calculation.

4.5.1 Construction of Criteria Hierarchy for the Decision Making

The first step is to build a criterion hierarchy for decision making. In this step, the criteria used for analysing the alternative products and the basic requirements concerning each

criterion are also defined. **Figure 4-3** provides a base to perform the algorithm in this thesis. Each criterion is assigned with significant attribute and each pair of alternatives can be judged by comparing between criteria. Once each comparison has been carried out through all the determining criteria, a winning DMU can be selected. For example, Criterion 1 of *Time* is compared with *Cost* between Alternative 1 of DMU_1 (multiple Decision Making Units defined in section 4.3) and Alternative 2 of DMU_2 . If the significant attribute for *Time* is defined with value which is bigger than *Cost*, the DMU linked with *Time* will be considered as priority. Once each comparison has been carried out through all the determining criteria, a winning DMU can be selected.

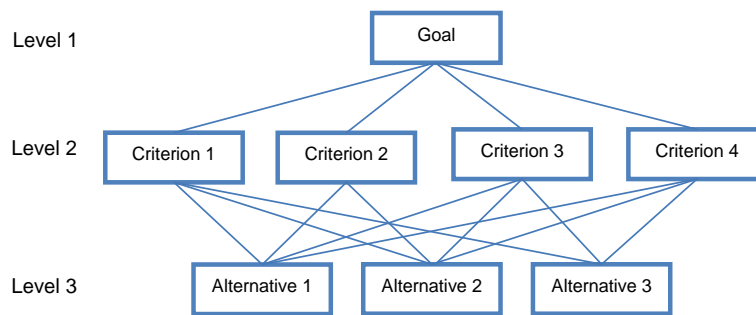


Figure 4-3: The AHP hierarchy

In this thesis a general AHP hierarchy model has been constructed based on the output of Criteria Generator. It composed of four levels as shown in **Figure 4-4**. Level 1 consists of the goal of choice of for selecting the most suitable product for project planning. Level 2 contains four main criteria, namely product time (duration), cost and quality. Level 3 encompasses eleven sub-criteria; it represents different intensities of the criterion. Level 4 consists of several alternatives; these can be used to reach the goal.

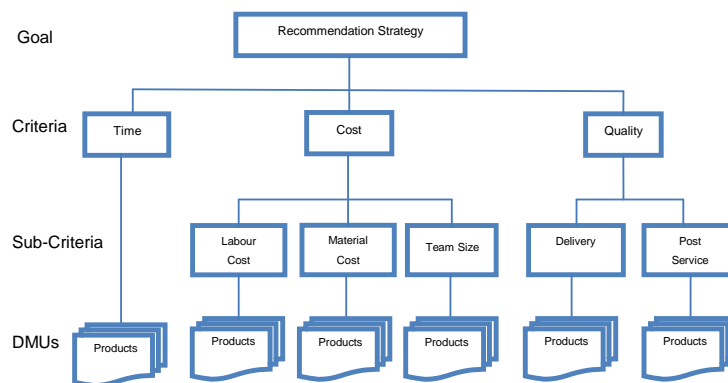


Figure 4-4: Four level hierarchy model for selection of best product

4.5.2 Pairwise Comparison of the Criteria and Sub Criteria

This step is to evaluate each of the covering criteria with respect to the goal. The criteria and sub criteria will be compared as to how important they are to the decision makers. The preferences judgment on pairwise comparisons is carried out by using Saaty’s discrete nine-point scale that is shown in **Table 4-9**.

Table 4-9: Saaty’s pair-wise comparison nine-point scale for AHP preference (2012)

Scale	Numerical rating	Reciprocal
Extremely importance	9	1/9
Very to extremely strongly importance	8	1/8
Very strongly importance	7	1/7
Strongly to very strongly importance	6	1/6
Strongly importance	5	1/5
Moderately to strongly importance	4	1/4
Moderately importance	3	1/3
Equally to moderately importance	2	1/2
Equally importance	1	1

The pair wise comparisons generate the matrix of rankings for each level of the hierarchy after all matrices are developed, then all pair wise comparisons and Eigen vectors (relative weights) are obtained.

The Eigen Vector method is to compare a set of “ n ” objects in pairs according to their relative weights. Denote the objects by $O_1, O_2...O_n$ and their weights by $W_1, W_2...W_n$, the pair wise comparisons can be represented by a matrix shown in **Table 4-10**.

Table 4-10: Matrix containing weights

	O_1	O_2	...	O_n
O_1	W_1/W_1	W_1/W_2	...	W_1/W_n
O_2	W_2/W_1	W_2/W_2	...	W_2/W_n
.
.
.
O_n	W_n/W_1	W_n/W_2	...	W_n/W_n

The matrix shown in Table 4-14 has positive entries everywhere and satisfies the reciprocal property $O_{ji} = 1/O_{ij}$. It is called a reciprocal matrix. The vector nw can be obtained if multiply this matrix by the transpose of the vector $W^T = (W_1, W_2, \dots, W_n)$.

Cells in comparison matrices will have a value from the numeric scale shown in **Table 4-10** to reflect the relative preference in each of the compared pairs. For example, if consider that *Time* is moderately important than the *Cost* factor in product deliverable, the *Time-Cost* comparison cell will contain the value 3. Mathematically this means that the ratio of the importance of *Time* versus the importance of *Cost* is three ($Time/Cost = 3$). Because of this, the opposite comparison, the importance of *Cost* relative to the importance of *Time*, will product the reciprocal of this value ($Cost/Time = 1/3$) as shown in the *Cost-Time* cell in the comparison matrix.

Once judgments have been entered, it is necessary to check that they are consistent. Consistency ratio $CR = \frac{CI}{RI}$ was applied for checking consistency in prioritisation. *CI* represents consistency index $\frac{\lambda_{max} - n}{n}$ and *RI* is Random consistency index. A size of 10 A paired comparison matrix contributed to the computation and the results in **Table 4-11** show that the Principal Eigen value λ_{max} was obtained from the summation of products between each element of Eigen vector and the sum of columns of the reciprocal matrix. $CR \leq 10\%$ must be satisfied for any inconsistency to be acceptable.

Table 4-11: *RI* with $n=10$ pair-wise comparison matrix.

<i>n</i>	1	2	3	4	5	6	7	8	9	10
<i>RI</i>	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

4.5.2.1 Criteria Pairwise Comparison

During this research, the experienced project managers and technical staff in engineering and manufacturing industries are met and consulted with the quality measurement issue. The ways of data collection of the weights of criteria and sub criteria that is applied for this phase are meeting, discussion and questionnaire. The following general judgments about all the comparisons of criteria were defined in terms of the collection data, shown as numbers in **Table 4-12**: *Time* is moderately important (3) over *Cost*; also *Cost* is equally to moderately important (2) over *Quality*. *Quality* is equally to moderately important (2) than *Cost*. Mathematical calculations have been applied to convert these judgments to priorities for each of the three criteria in Priority Vector column. Of course these weights of criteria and sub criteria can be changed in lights of user experience if the customer requirements or environment are changed.

The comparison matrix (**Table 4-12**) shows the pairwise relative priorities for the criteria. Now overall priorities or weights of the criteria need to be calculated. It requires the normalization of the comparison matrix firstly (**Table 4-13**).

Table 4-12: Pairwise comparison matrix with intensity judgments

Criteria	Time	Cost	Quality
Time	1	3	2
Cost	1/3	1	1/2
Quality	1/2	2	1
Total	1.8333	6.0000	3.5000

Next, divide each cell by the total of the column (**Table 4-13**) (e.g., for the *Time* column: $1/1.8333 = 0.5455$). The normalized matrix is shown in **Table 4-13**.

Table 4-13: Normalized matrix

Criteria	Time	Cost	Quality
Time	0.5455	0.5000	0.5714
Cost	0.1818	0.1667	0.1429
Quality	0.2727	0.3333	0.2857
Total	1.0000	1.0000	1.0000

From this normalized matrix, the overall or final priorities (**Table 4-14**) can be obtained by simply calculating the average value of each row (e.g., for the *Time* row: $(0.5455 + 0.5000 + 0.5714)/3 = 0.5390$).

Table 4-14: Level 1 pair-wise comparison results

Criteria	Time	Cost	Quality	Priority Vector
Time	1.0000	3.0000	2.0000	<i>0.5390</i>
Cost	0.3333	1.0000	0.5000	<i>0.1638</i>
Quality	0.5000	2.0000	1.0000	<i>0.2973</i>
Total	1.8333	6.0000	3.5000	1.0000

According to the results in **Table 4-14**, it is clear that more importance is given to the *Time* criterion (0.539), followed by *Quality* (0.2973). The *Cost* factor has a minimum weight (0.1638) in the selection decision. These priorities have mathematical validity, as measurement values derived from a ratio scale, and have also an intuitive interpretation. From **Table 4-14**, the *Time* has 53.9% of the overall importance of the criteria can be interpreted, followed by *Quality* with 29.73% and *Cost* (16.38%) respectively.

Once judgments have been entered, it is necessary to check that they are consistent. Start with the matrix showing the judgment comparisons and derived priorities (**Table 4-15**), then use the priorities as factors (weights) for each column as shown in **Table 4-15**.

Table 4-15: Priorities as factors

Criteria	Time	Cost	Quality
Criteria Weights =>	0.5390	0.1638	0.2973
Time	1.0000	3.0000	2.0000
Cost	0.3333	1.0000	0.5000
Quality	0.5000	2.0000	1.0000

Multiply each value in the first column of the comparison matrix in **Table 4-15** by the first criterion priority (i.e., $1.000 \times 0.5390 = 0.5390$; $0.3333 \times 0.5390 = 0.1796$; $0.5 \times 0.5390 = 0.2695$) as shown in the first column of **Table 4-16**; multiply each value in the second column of the second criterion priority; continue this process for all the columns of the comparison matrix (in our example, we have three columns). **Table 4-16** shows the resulting matrix after this process has been completed. Next, add the values in each row to obtain a set of values called weighted sum as also shown in **Table 4-16** (e.g. the *Time* row: $0.5390 + 0.4914 + 0.5946 = 1.625$)

Table 4-16: Calculation of weighted columns and weighted sum

Criteria	Time	Cost	Quality	Weighted Sum
Time	0.5390	0.4914	0.5946	1.625
Cost	0.1796	0.1638	0.1487	0.492
Quality	0.2695	0.3276	0.2973	0.894

Next is to divide the elements of the weighted sum vector by the corresponding priority of each criterion as shown in **Table 4-17**. Calculate the average of the values

Table 4-17: Calculation of average of the values

Weighted Sum	Criteria Weights	Average of the value
1.625	0.5390 (Time)	3.015
0.492	0.1638 (Cost)	3.004
0.894	0.2973 (Quality)	3.008

$$\lambda_{\max} = (3.015 + 3.004 + 3.008) / 3 = 3.009$$

Now the consistency index (CI) can be calculated as follows:

$$CI = (\lambda_{\max} - n) / (n - 1) = (3.009 - 3) / (3 - 1) = 0.0046$$

where n is the number of compared elements (in this case $n = 3$).

Now the consistency ratio can be calculated and defined as: $CR = \frac{CI}{RI}$

RI is the consistency index of a randomly generated comparison matrix defined in **Table 4-11**.

It can be seen from **Table 4-18** that for $n = 3$, $RI = 0.58$, therefore

$$CR = CI / RI = 0.0046 / 0.58 = 0.00793 \leq 0.1$$

Table 4-18: *RI* with $n=3$ pair-wise comparison matrix.

<i>n</i>	2	3	4	5
<i>RI</i>	0	0.58	0.9	1.12

Since this value of 0.0793 for the proportion of inconsistency *CR* is less than 0.10, it is assumed that the judgments matrix is reasonably consistent so the process of decision-making can be continued by using AHP.

4.5.2.2 Sub Criteria Pairwise Comparison

This step is to judge and compare each of the sub criteria by applying the same principle and evaluation approach. Project management experts define the following general judgments about the sub-criteria (*Material*, *Labour*, *Team Size*) comparisons of the *Cost*, shown as numbers in **Table 4-19** like this: *Labour Cost* is moderately important (3) over *Material Cost*; also *Material Cost* is moderately important (3) over *Team Size*. *Labour Cost* is very strong important (7) than *Team Size*. Mathematical calculations have been applied to convert these judgments to priorities for each of the three criteria in Priority Vector column.

The comparison matrix (**Table 4-19**) shows the pairwise relative priorities for the sub-criteria. Now overall priorities or weights of the sub-criteria of *Cost* need to be calculated. It requires the normalization of the comparison matrix firstly.

Table 4-19: Pairwise comparison matrix with intensity judgments

Criteria	Material	Labour	Team Size
Material	1	1/3	3
Labour	3	2	7
Team Size	1/3	1/7	1
Sum =	4.3333	1.4762	11.0000

Divide each cell by the total of the column (**Table 4-19**) (e.g., for the *Material* column: $1/4.3333 = 0.2308$). The normalized matrix is shown in **Table 4-20**.

Table 4-20: Normalized matrix

Criteria	Time	Cost	Quality
Material	0.2308	0.2258	0.2727
Labour	0.6923	0.6774	0.6364
Team Size	0.0769	0.0968	0.0909
Total	1.0000	1.0000	1.0000

From this normalized matrix, the overall or final priorities (**Table 4-21**) can be obtained by simply calculating the average value of each row (e.g., for the *Material* row: $(0.2308 + 0.2258 + 0.2727)/3 = 0.2431$).

Table 4-21: Level 2 pair-wise comparison results

Criteria	Material	Labour	Team Size	Priority Vector
Material	0.2308	0.2258	0.2727	<i>0.2431</i>
Labour	0.6923	0.6774	0.6364	<i>0.6687</i>
Team Size	0.0769	0.0968	0.0909	<i>0.0882</i>

Multiply each value in the first column of the comparison matrix in **Table 4-22** by the first criterion priority (i.e., $1.000 \times 0.2431 = 0.2431$; $3.0000 \times 0.2431 = 0.7293$; $0.3333 \times 0.2431 = 0.0081$) as shown in the first column of **Table 4-22**; multiply each value in the second column of the second criterion priority; continue this process for all the columns of the comparison matrix (in this example, we have three columns). **Table 4-23** shows the resulting matrix after this process has been completed. Next, add the values in each row to obtain a set of values called weighted sum as also shown in **Table 4-23** (e.g. the *Material* row: $0.2431 + 0.2229 + 0.2646 = 0.7306$)

Table 4-22: Priorities as factors

Criteria	Material	Labour	Team Size
Criteria Weights =>	<i>0.2431</i>	<i>0.6687</i>	<i>0.0882</i>
Material	1.0000	0.3333	3.0000
Labour	3.0000	1.0000	7.0000
Team Size	0.3333	0.1429	1.0000

Table 4-23: Calculation of weighted columns and weighted sum

Criteria	Material	Labour	Team Size	Weighted Sum
Material	0.2431	0.2229	0.2646	<i>0.7306</i>
Labour	0.7293	0.6687	0.6174	<i>2.0154</i>
Team Size	0.0081	0.0956	0.0882	<i>0.2648</i>

Next is to divide the elements of the weighted sum vector by the corresponding priority of each criterion as shown in **Table 4-24**. Calculate the average of the values

Table 4-24: Calculation of average of the values

Weighted Sum	Criteria Weights	Average of the value
<i>0.7306</i>	<i>0.2431 (Material)</i>	3.005
<i>2.0154</i>	<i>0.6687 (Labour)</i>	3.013
<i>0.2648</i>	<i>0.0882 (Team Size)</i>	3.002

$$\lambda_{\max} = (3.005 + 3.013 + 3.002) / 3 = 3.00708$$

Now the consistency index (CI) can be calculated as follows:

$$CI = (\lambda_{\max} - n) / (n - 1) = (3.00708 - 3) / (3 - 1) = 0.003539$$

where n is the number of compared elements (in this case $n = 3$).

Now the consistency ratio can be calculated and defined as: $CR = \frac{CI}{RI}$

It can be seen from **Table 4-18** that for $n = 3$, $RI = 0.58$, therefore

$CR = CI/RI = 0.03539/0.58 = 0.06101 \leq 0.1$, since CR value is less than 0.10, it is assumed that the judgments matrix is reasonably consistent.

Therefore the priority for *Material Cost* = $0.1638 \times 0.2431 = 0.03980$, priority for *Labour Cost* = $0.1638 \times 0.6687 = 0.1095$, priority for *Team Size* = $0.1638 \times 0.0882 = 0.0144$.

Project experts make the following judgments about the sub-criteria (*Delivery Quality*, *Post Service Quality*) comparisons of the *Quality*, shown as numbers in **Table 4-25** like this: *Delivery* is moderately to strongly importance (4) over *Post Service*. Mathematical calculations have been applied to convert these judgments to priorities for each of the three criteria in Priority Vector column.

Table 4-25: Pairwise comparison matrix with intensity judgments

Criteria	Post Service	Delivery
Post Service	1	1/4
Delivery	4	1
Sum =	5	1.25

As there are only two sub criteria, the calculation is simple as shown in **Table 4-26**.

Table 4-26: Level 2 pair-wise comparison results

Criteria	Post Service	Delivery	Priority Vector
Post Service	0.2000	0.2000	0.2000
Delivery	0.8000	0.8000	0.8000

In term of **Table 4-18**, the judgments matrix is always consistent if the number of compared elements is two. Therefore the priority for *Delivery* = $0.2973 \times 0.8 = 0.2229$, priority for *Post Service* = $0.2973 \times 0.2 = 0.074$.

Table 4-27 shows the priorities are derived for all sub criteria, the total priority equals 1.

Table 4-27: Derived priorities for the sub criteria against each of the products

Sub-criteria	Duration	Material Cost	Labour Cost	Team Size	Post Service	Delivery	Total
Priority	0.5390	0.03980	0.1095	0.0144	0.074	0.2229	1.0000

4.5.3 Criteria Weight Aggregation and Priority Calculation

In the final step, the overall weighted average rating and priority needs to be calculated for each alternative; which means priorities that take into account the fact that each criterion has a different weight. Formally, the weighted summary (Hosseini *et al.*, 2015) of a non-empty set of data

$$[x_1, x_2, \dots, x_n]$$

with non-negative weights (%)

$$[w_1, w_2, \dots, w_n]$$

is the quantity

$$\text{Weighted Sum}_x = w_1x_1 + w_2x_2 + \dots + w_nx_n \quad (4)$$

At this point, all the comparisons for criteria and sub criteria have been made, and the developed algorithm has derived the local priorities for each product at each level. Since how much the priority of each criterion and sub-criterion contributes to the priority of the goal is known, the global priority of each sub-criterion can be calculated. Notice that *Cost* and *Quality* will not be evaluated directly, but that each of their sub criteria will be evaluated on its own (**Table 4-28**). The global priorities throughout the hierarchy will add up to 1.0000.

The calculations for each DMU are shown below in terms of formula (4) and the results are presented in **Table 4-28** following the convention of showing the local priorities and the weights for each criterion.

Overall Priority of the P1: $0.9 \times 0.5390 + 0.83 \times 0.0398 + 0.9 \times 0.1095 + 1 \times 0.0144 + 1 \times 0.074 + 0.8 \times 0.2229 = 0.8838$

Overall Priority of the P2: $0.8 \times 0.5390 + 0.83 \times 0.0398 + 1 \times 0.1095 + 0.9 \times 0.0144 + 0.9 \times 0.074 + 0.9 \times 0.2229 = 0.8543$

Overall Priority of the P5: $0.8 \times 0.5390 + 0.67 \times 0.0398 + 0.8 \times 0.1095 + 0.8 \times 0.0144 + 0.9 \times 0.074 + 0.8 \times 0.2229 = 0.8023$

Table 4-28: Global priorities for the recommended product decision

Choose the best product								
DMUs (Product)	Criteria	Time	Cost			Quality		Overall Score
	Sub-criteria	Duration	Material Cost	Labour Cost	Team Size	Post Service	Delivery	
P1		0.9	0.83	0.9	1	1	0.8	0.883827
P2		0.8	0.83	1	0.9	0.9	0.9	0.854297
P5		0.8	0.67	0.8	0.8	0.9	0.8	0.802284
Totals	Priority weights (Sub-criteria)	0.5390	0.0398	0.1095	0.0144	0.074	0.2229	
	Priority weights (Criteria)	0.5390	0.1638			0.2973		1.0000
		1.0000						

In above table, the overall weighted average rating and preference priority for each DMU product is calculated and totalled. Based on the principles of AHP, a rank for the DMUs is produced and recommended as *PI* with the highest score satisfies the selection strategy in terms of this product meets the customers' request.

Since the project are broken down to many simple products based on PRINCE2, in the case of many the same products found from historical data repository, the benchmarking and recommendation principle developed in this research can be applied to choose suitable products. The activities associated with the chosen products will be regarded as the most suitable practices to deliver the products. Finally, all chosen products with most appropriate practice will be integrated to make a new project plan.

4.6 Summary

This chapter presents a product benchmarking and product recommendation method which supports decision making and enhances performance of project planning and monitoring. This novel method consists of four stages: the first stage is to generate criteria through a product preliminary analysis which is essential to product based benchmarking process as it specifies the requirements of the final project being delivered. The outcomes of the analysis constitute suitable selection criteria for a product pre-selection to meet customer requests.

In most cases of engineering and manufacturing industries, benchmarking is among a large amount of data the average isn't giving the expected results, project users would like to see a range of benchmarked results. Quartile approach provides such a benchmarking process as stage two to find and shortlist a reasonable range of best practice products from massive stored product portfolios.

In stage three, Data envelopment analysis (DEA) is utilised to measure efficiency of multiple Decision Making Units (DMUs) when a further selection of products presents a structure of multiple inputs and outputs, it helps to define the alternative products from benchmarked products shortlist.

In order to recommend a winning DMU for the request, AHP based approach is employed to enable decision makers to take into account both quantitative and qualitative criteria of the products in the final stage. Firstly a hierarchy for the decision needs to be built, next the

relative priorities (weights) for the criteria and sub criteria need to be derived, then each of the elements with respect to these criteria needs to be evaluated to check that they are consistent, at last the overall weighted average rating and preference priority to be calculated and totalled for each alternative. This process facilitates an optimisation of the competitive products and determines then a ranking for the winning product(s). The business intelligence generated from Quartile, DEA and AHP can be used to aid a decision on the best-fit products for customers' needs.

Chapter 5. Intelligent Project Automation Systems - iPAS

The novel PBIS framework is represented in Chapter 3 and Chapter 4. Various methods and techniques are described and put together in the PBIS framework guidelines. The focus of this chapter is a web based project management software iPAS that achieves the main goals of PBIS framework.

5.1 Motivation of iPAS Tool

In a project environment, project management can support the achievement of project and organisational goals, and provide a greater assurance to stakeholders that resources are being managed effectively. A lot of project managers are looking for good software which is easy to use and to understand and, most of all, which is reliable and profitable.

As described in Chapter 4, a framework PBIS is proposed to benchmark and recommend product portfolios for project planning and monitoring. How to utilise this framework for managing projects efficiently and everybody can use every day is emerging. With the aim of improving management life, a software iPAS was developed to achieve the goals of the PBIS framework in this thesis. This software tool is able to intelligently assist the management of the whole life cycle of projects base on the best practices from other projects, it is able to automatically deliver project plans to match customer requirements and provides a mechanism for continuous monitoring of project execution via benchmarking and generation of project reports. The main technique and mechanism such as product based planning, portfolio management and benchmark mechanism of PBIS framework have been transformed to respective system functions such as project planning, project monitoring and project reporting in iPAS.

The iPAS system was developed by applying Microsoft .NET technology which takes advantage of many features of the .NET framework 4.5, such as the SQL data source API, integrated AJAX support, Web Services, and a security model that protects data even in Internet applications.

5.2 Overview of iPAS Functions

Since iPAS has been implemented, the developed system functions can be reviewed by looking back to the requirements from client that it should be used at different stages of a project lifecycle: Bidding stage to prepare tender document; Project planning, Project progress monitoring and Project report. As a web based project management system, iPAS was designed to be able to intelligently support project managers in project planning, optimising business performance and project cost. In addition, the other main facilities provided by the system are: reverse planning, human resource management and profiling, project monitoring and project reporting. Each of the facilities will be introduced in the following sections.

5.2.1 Project Planning

Planning is essential to the successful execution of any projects. It is part of project management, which relates to the use of schedules such as Gantt charts to plan, monitor the execution of work and subsequently report progress within the project environment. iPAS enables project managers to plan a project by following pre-defined products (or work packages) in light of PBS and PFD. It's also the key step of the product-based planning technique in PRINCE2 which has emerged based upon the idea of considering the products that will result from the project rather than how to execute the work.

A. Project and performance criteria configuration

iPAS can be utilised when project products are refined through PBS and PFD. In order to make a new project plan, first of all user needs to provide some basic project information as shown in **Figure 5-1**, which displays a form with entered information of a new project, include giving project name, selecting project start date and end date, defining Time and Cost *Tolerance Level* (%) which will be used to define the boundaries of the project tolerance chart in project portfolio page, selecting customer and project manager, etc. User can also create a new customer if there is no desired record available from the customer dropdown list. On the right hand side of the page there is a small table with light blue boundaries that allows user to choose available super groups for a new project; also user may create new super groups to add them into the list one by one. Please note the logo “Dytecna” shown on the top left of **Figure 5-1** is an internal logo used by case study Company A.

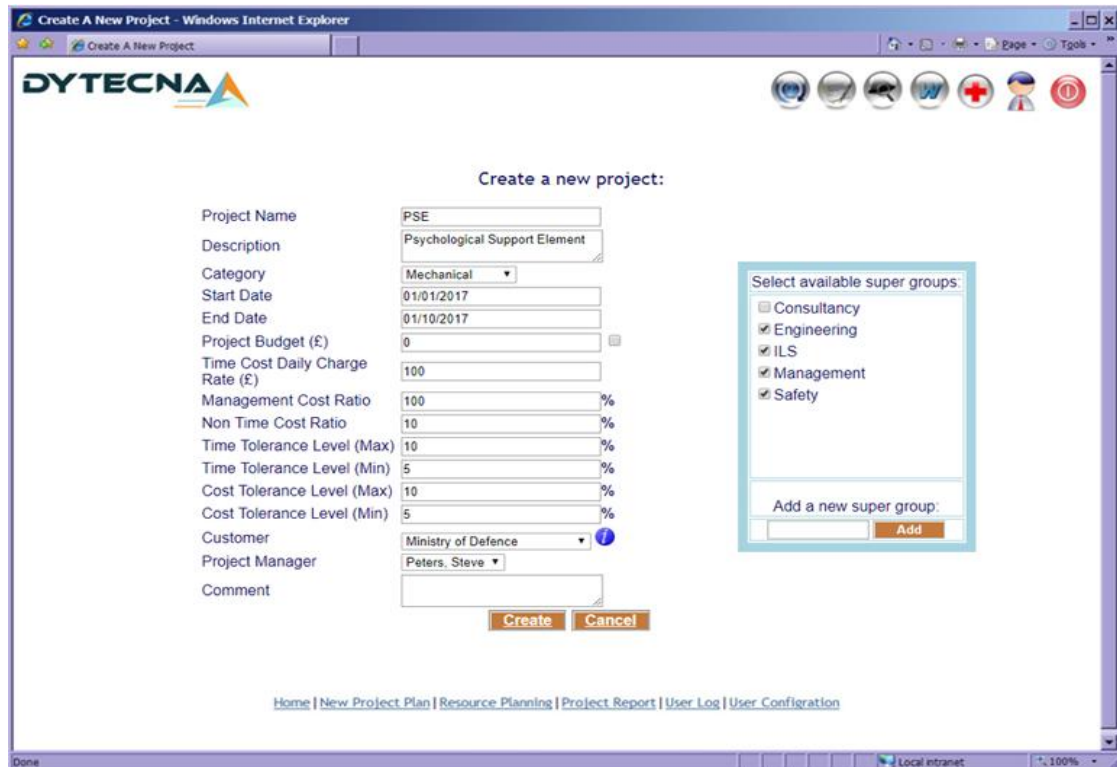


Figure 5-1: Create A New Project Page

Before proceeding the plan generation, user needs to set up the project performance criteria in terms of the articulation results from Project Brief or ITT in order to benefit from the built in Product Benchmarking and Recommendation Engine. Firstly, user needs to setup the benchmarking **Project Plan Build Priority** (either *Time* or *Cost*) depends on which criterion is more important to that project. If project completion *Time* is chosen as the first priority, the project *Cost* will be automatically become second priority, vice versa. Then user will need to choose a quartile value for each criterion as the **Criteria Expectation** accordingly. The criteria levels can be selected from Maximum, Upper Quartile, Medium, Lower Quartile and Minimum five levels.

This setting is used to benchmark the products in the ranges, those products meet both the criteria on *Time* and *Cost* will be regarded as the best practice results for further ranking and qualification. Secondly, user will need to set up the performance criteria. Each criterion will be assigned with significant attribute against others in the same criteria group based on **Table 4-13**. The data collection of the weights of criteria and sub criteria then will be used for product further selection and recommendation mechanism. The *General Criteria* is the top level criteria (see **Table 4-1**) setup for all projects, followed by the sub criteria groups *Cost Criteria* and *Quality Criteria*. *Time* doesn't have sub criteria as a product attribute, but it can be divided into sub criteria if it's needed in some scenarios. User is able to add new criteria

group or add criteria to each criteria group if more product attributes need to be assessed and adjusted.

B. Planning when existing groups or products are found

After project general information and performance criteria are configured, user can produce a new project plan via product benchmarking and recommendation machinima based on desired criteria from previous practices.

In terms of the chosen groups of the new project, matched historical projects will be listed out on the left hand side of the page. User then is also able to copy all products from a particular project completed before, or choose the most desirable project(s) from the completed project list to copy. Please be aware, either way it assumes that user already has the product breakdown structure of the project on hand. As long as the products together with their associated activities are selected from the desirable project(s) and submitted for assembling; the product portfolios with the details (e.g. product name, activity name, dependencies and feedback) will be copied cross to the new project. The effort (e.g. time and cost) of each activity will be calculated based on the customised benchmarking criteria and product recommendation algorithms discussed in Chapter 4. As a result, a new project Gantt chart will be generated according to the time effort similar to **Figure 5-2**. Of course, such automatically derived project plan allows manual overrides by privileged users for special considerations such as adding a new product or activity, removing unnecessary products or editing the statistics of the effort before the project starts.

C. Planning when existing groups or products are not found

However, it is not essential to use historical data to create a new project plan in iPAS. Apart from creating a project plan in iPAS based on existing groups and products from completed projects, user is also able to manually add new groups (as shown in **Figure 5-2**) or new products and attach activities underneath if the groups or products do not exist in product based project portfolio repository.

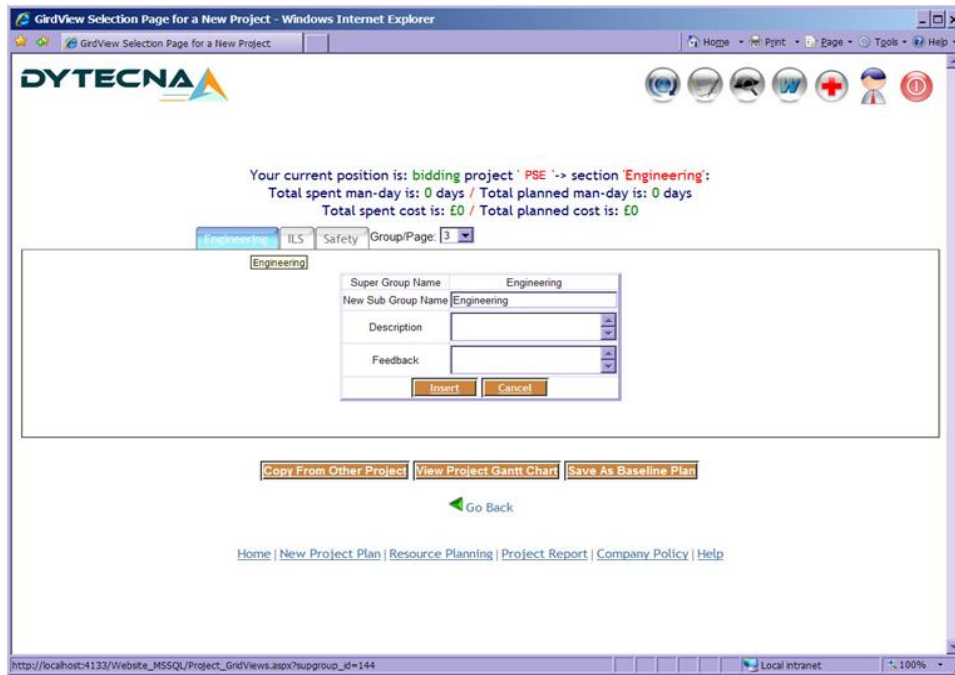


Figure 5-2: Configure Project Products

For example, the details of the new products (e.g. name, total estimation effort of time and cost, etc.) and associated activities (e.g. name, estimation effort of time and cost, required skills, dependencies etc.) can be manually entered into the system. At this point, activities may also be assigned to resources for realisation. The system then will automatically produce a project interactive Gantt chart with dependencies according to the time effort of each activity. By clicking on the individual product bar in the interactive Gantt chart as shown in **Figure 5-3**, user will be brought to another level of the interactive Gantt chart - activities charts of this product (illustrated in **Figure 5-4**). The two bars (Blue and Green) under the columns “Man Days” and “Total Cost” present the Earned Values (Phillips, 2016), which provide basis to assess product progress against the baseline plan - time and cost performance. The Earned Values provide data for pro-active management action and provide users with a summary of effective decision making. User could also see the details of an individual activity by clicking the activity bar, and user is able to edit the details of products or activities according to their assigned privilege. For example, a team leader is able to click the Gantt chart in product page to look up the details of each activity and amend the information such as reallocate human resources (either by person or by gang in terms of their availabilities) and tick the completion box when activity is completed.

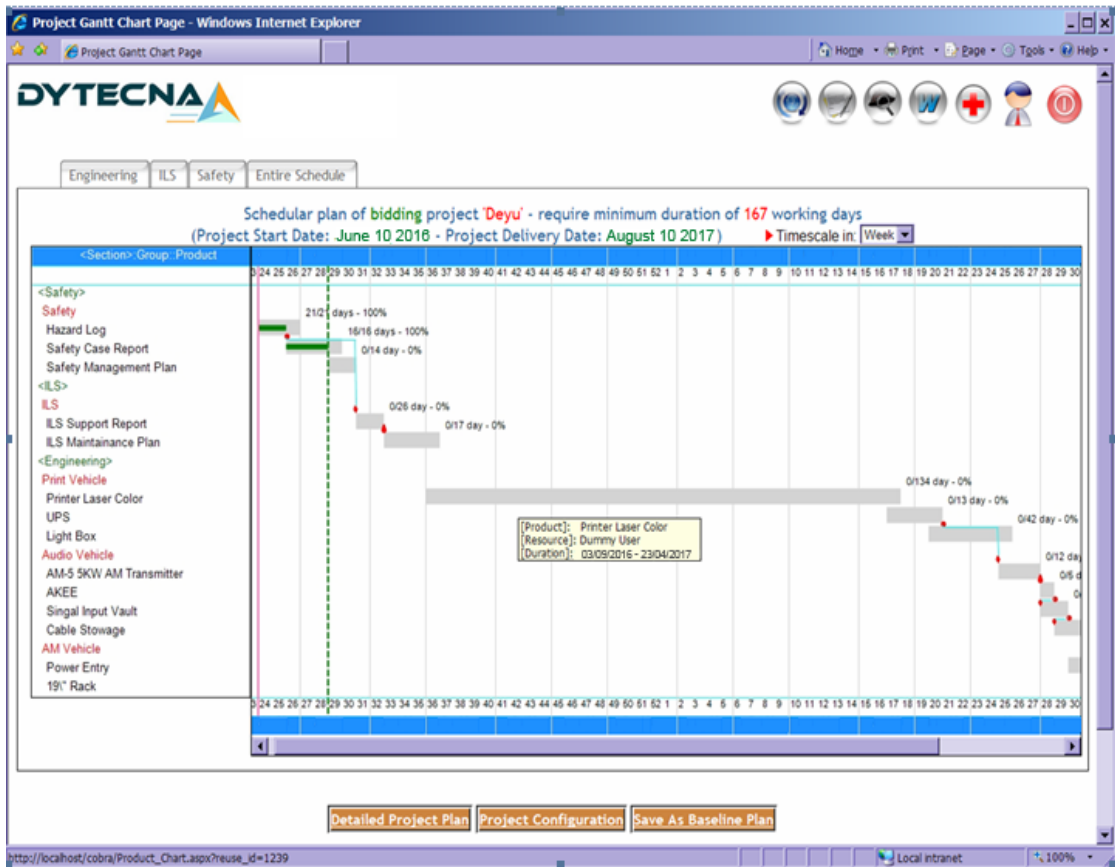


Figure 5-3: A Project Gantt Plan

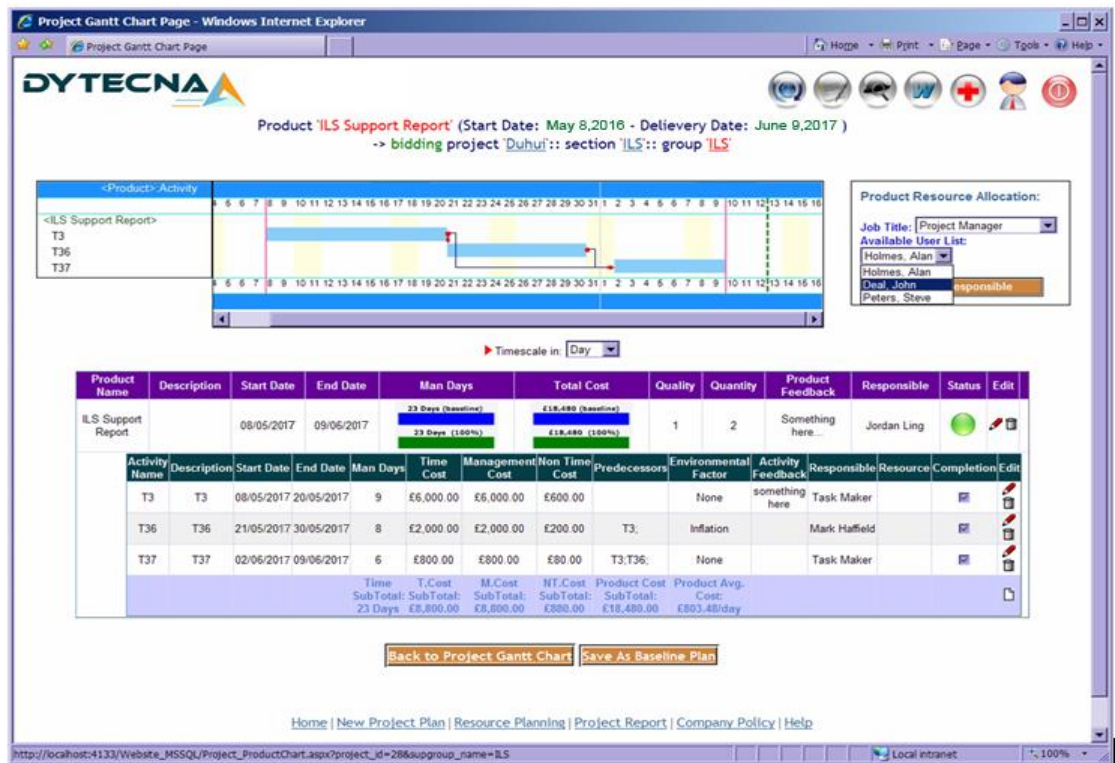


Figure 5-4: A Product with Associated Activities

D. Reverse Planning

In addition, iPAS also enables reverse planning which allows user to amend the project ending date or start date after the project plan has been generated, the project plan and Gantt chart will automatically adjust to fit the new duration. Activities within a specific product may be moved from a time order to be overlapped with each other when the duration of the product is compressed. In this case, the attention will be drawn to the person who is responsible for, as that s/he may not accommodate some of the overlapped dates after product duration is compressed, extra resources may therefore be required. Finally user is able to save the new project plan as a new baseline if changes are approved, as it is a major task to keep track of all the changes and at any time without referring to the latest version.

5.2.2 Human Resource Management and Profiling

The feature of human resource management in iPAS provides a function to manage the staff resources and the time slots related to their responsibilities in the business. One key result of project plan is the staff allocation plan which depicts how and when project team members are assigned to the products and associated activities, and how the team members are released from the project. The iPAS tool provides a basic management of staff resource allocation and activity assignment. It has an embedded feature to allow the project manager to authenticate staff's work absences and record the period absent, such as sickness, public holidays and off-site training for all project team members. With the help of this feature, the project manager is able to assign available skilled staff into project products (or work packages) and activities (shown in **Figure 5-5**).

The data of staff allocation together with other project portfolios stored in the database could be used for generating live project resource allocation reports and other analytical reports. The human resource allocation report is useful to project manager and the programme officer, as it truly illustrates how the project is staffed in the whole project time frame and where project resource conflicts occur. If a team member is over-employed, his or her resource data will be automatically highlighted in the report to attract attention, then the project manager or programme officer is expected to re-allocate some of the work to other team members so that the workload of this member is below the standard quota. Furthermore, if one or more of the activities are cancelled, or the project plan has changed; the system will release time effort from allocated staff members. The information on human resource allocation could be used for rewarding and promoting desired team performance and work attitudes.

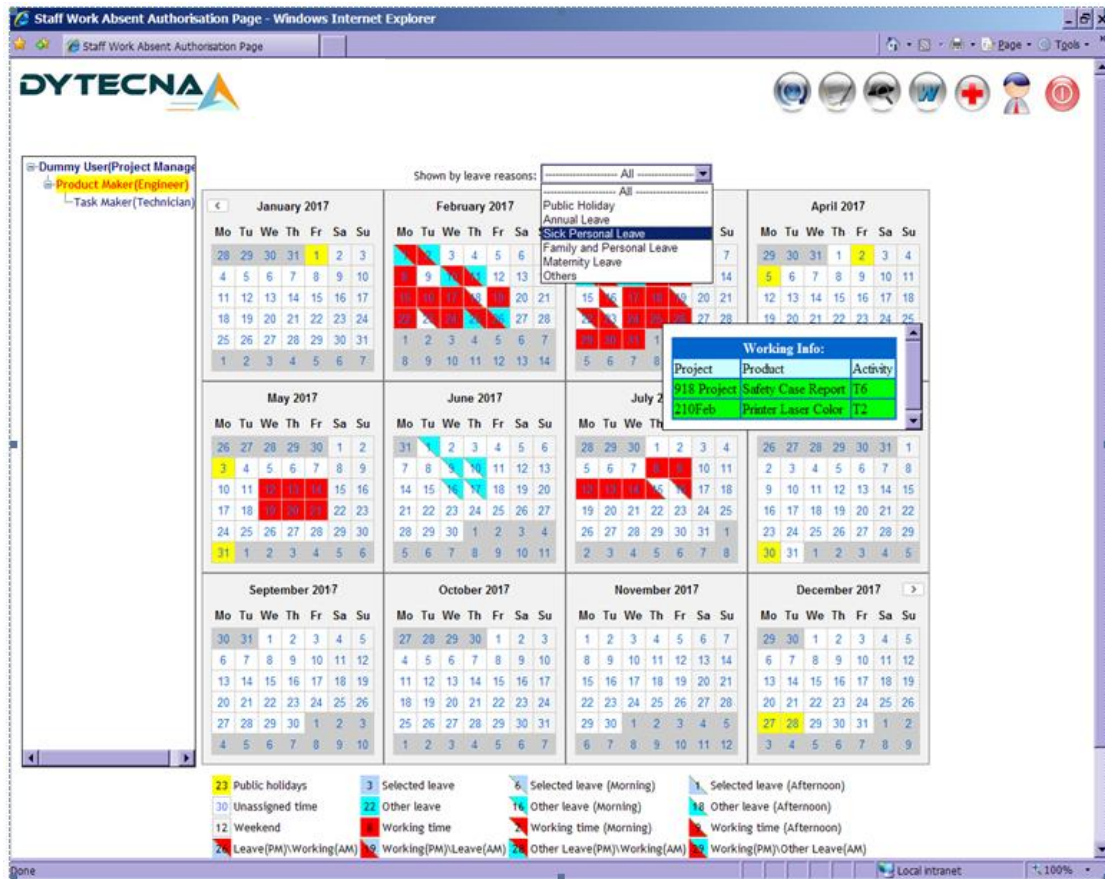


Figure 5-5: Human Resource Management Page

5.2.3 Project Monitoring and Alert Mechanism

In many cases, the delivery dates of project products are estimated using expert judgement, thus many project managers will evaluate progress by ad-hoc discussions with the team members. Actual effort is not easy tracked and this measurement of progression is not very precise, subjective, and often leads to late discovery of schedule slippage, making it hard to meet agreed deadlines. It is also difficult to assess the impact of changes to user requirements and resource allocation. Moreover, to manage a project well, it is very much about establishing good communication and managing risk. Communication can be facilitated by proper application of information technology. Risk can be dealt with if the correct information for decision making is available.

Thus it is crucial to have a reliable mechanism to monitor the runtime project progress and early alert facility to warn project managers and project team leaders of potential programme anomalies. iPAS provides such a mechanism to automatically monitor and analyse product effort values and work completion status during the project progress according to saved project baseline. It is designed to be a central source for all project data and provide all

project stakeholders with an immediate view of actual project progress, supporting the decision making and controls to reduce the need for meetings or reports thus freeing the project manager to manage the project. The project monitoring mechanism of iPAS depends on the regularly entering the actual effort spent by each person or team assigned to the specific activity as soon as that specific activity is completed. The responsible person is also required to enter real effort to complete a task and to comment on environmental factors affecting the delivery result. When the completion box of an activity is ticked, the activity is considered completed. Since activities are associated to products, actual effort can be summarised at product level and even at project level.

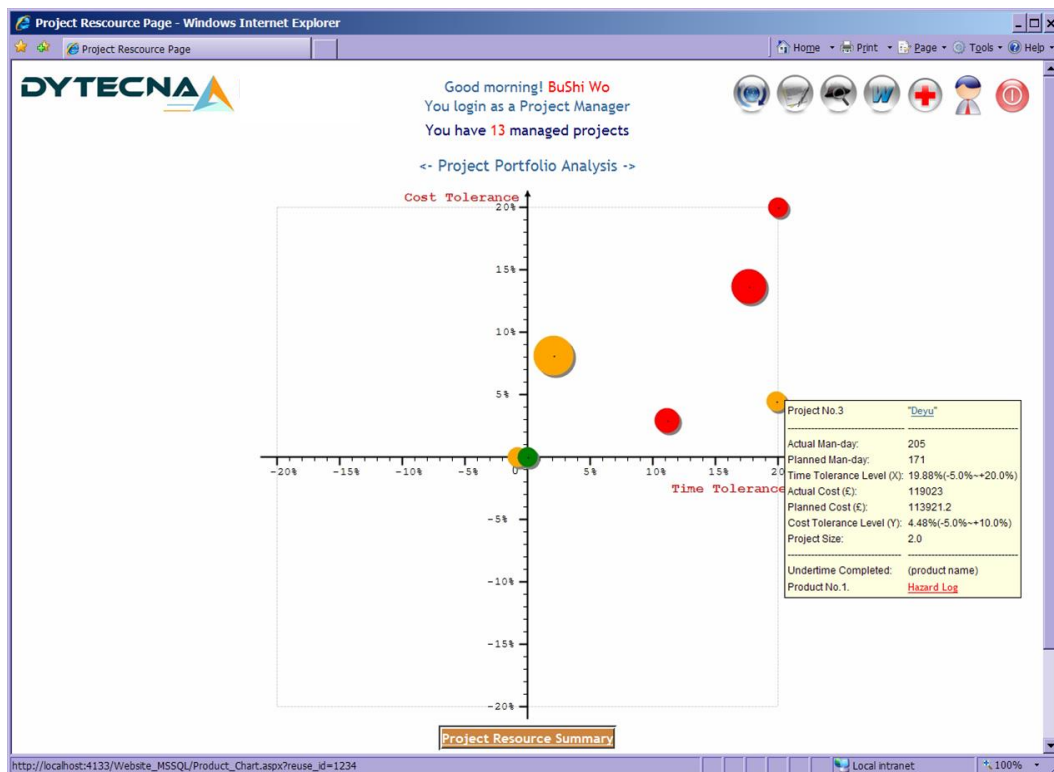


Figure 5-6: The Project Tolerance Grid

Meanwhile, senior members of the project such as project managers or executives are able to check the progress status of all current running projects immediately through a project tolerance Grid chart (shown in **Figure 5-6**) after login. This chart provides a project alerting mechanism. There are two levels of alerting mechanism in iPAS: one is at project level and one is at product level. During the project progress, if the position of a project is inside the tolerance level boundaries but may be over time, over budget or both; the bubble colour will be shown as amber which means the project is still under control but needs to be carefully monitored. The project manager is expected to investigate the issue or look for extra resources. If the position of a project is outside the tolerance level boundaries, the bubble

colour will be shown as red which means it is beyond the project tolerance level. This situation requires an exception plan to be launched in accordance with PRINCE2 processes. The project bubble colour will be shown as green if the project is on time and on budget. From this Grid view, user (dependent on privileges), is also able to click through the links of listed products and find more details from product view.

For each product, there is also a status traffic light indicator designed for project manager to understand what is due, what is completed and what is overdue (shown in **Figure 5-4**). If a product is not completed yet but still within the planned time frame and one or more activities are over time, over budget or both; the status traffic light of this product will be shown as Amber. The traffic light will be shown as Red if the product is completed but either it's over time or over budget, or the product is uncompleted within planned time. In this case, corrective action will have to be taken when necessary in order to meet project objectives in terms of effort and schedule. The bubble will also show Red if the project is under time, under budget or both beyond the tolerance level. This situation requires an interrogation to establish the reason because some work may have been omitted or profit levels excessive.

5.2.4 Project Reporting

iPAS is able to generate different kinds of reports with charts according to customer requirements. Having used a data repository, the actual effort of each activity can be recorded when it is completed. In that case, status reporting would accurately reflect the real progress of the project status. For instance, system is able to benchmark current project data against data held from previous projects and provide comparison reports, which juxtapose the planned resource usages for the various products with their actual resource usage. Benchmarked data will be recorded in a central database at the end of the project to improve the analysis available for subsequent projects. From an entered project configuration, iPAS is also able to generate and summarise output reports which detail the project costs and time. These reports demonstrate project performance, cost analysis, trend analysis, resource allocation and real-time project status etc. as shown in **Figure 5-7**. All these reports can be exported into varied formats such as PDF, MS Excel and Word. As senior members of project team, they should be able to identify potential or real problems and the critical resources associated with the reports.

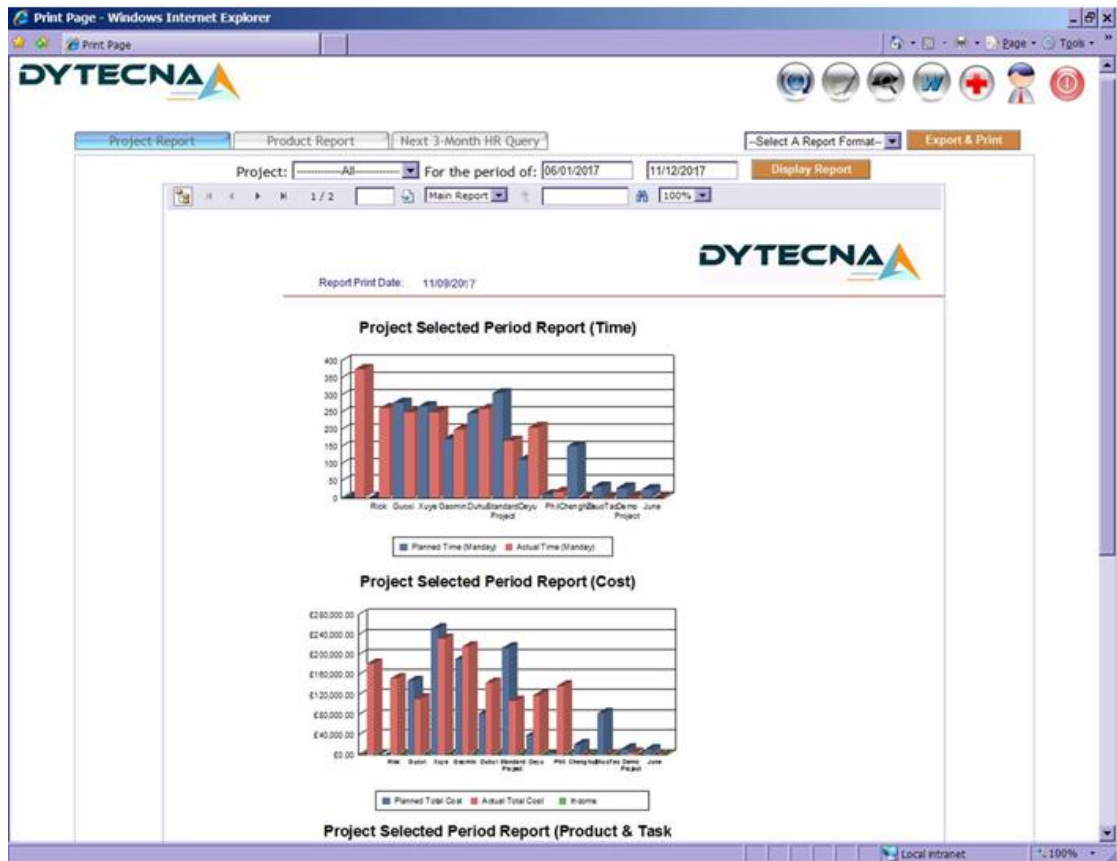


Figure 5-7: Project Report

It is recognised that getting everyone consistently using the product based planning method and share project information across entire project team and organisation is not easy. iPAS has been developed to bridge the gap between PRINCE2 main principles and its application, with providing the user the features of automated planning, monitoring, management reports and human resource allocation. iPAS allows configurable access levels based on roles and rights and responsibilities granted at the various management levels and offers customisation features based on respective establishment needs. This flexible approach ensures each user need only see the functionality and information necessary to perform their responsibilities; thereby making the application easier to use for all stakeholders. iPAS also provides a complete project central database, storing all project data in one location for easy access, saving time and resources. It has built in deliverables' reviews and authorisations are granted online for multi-level granularity cooperation; progress is updated in real time to reduce the need for costly time wasting meetings. All project members can access to and share real time project information, best practices and learn from previous project experiences; thus providing more accurate estimating and planning across network or an intranet.

In addition, iPAS was designed generically; therefore it can be widely used for different industries such as manufacture, education, medicine, construction and rail, etc. The report formats also can be customised according to the requirements from specific users.

5.3 Summary

This chapter described iPAS software has been implemented to achieve the main goals defined in PBIS framework, such as capture, store and share product based portfolios with engaging the product benchmarking and recommendation mechanism.

Getting everyone consistently using the product based planning method and sharing project information across entire project team and organisation is not easy. iPAS has been developed to bridge the gap between PRINCE2 main principles and its application, providing the user with automated planning, monitoring, reports and human resource allocation. iPAS allows configurable access levels based on roles and rights granted that allow users to access the various management levels and features of the solution based on their individual needs. This approach ensures that each user need only see the functionality and information necessary to perform their responsibilities, thereby making the application easier to use for all stakeholders. iPAS also provides a complete project central database, storing all project data in one location for easy access, saving time and resources. It has built in deliverables' reviews and authorisations are granted online for multi-level granularity cooperation, and progress is updated in real time to reduce the need for costly meetings and expensive time wasting. Accessed across network or intranet, all project staff can share real time project information, best practices and learn from previous experiences with projects; all these enable more accurate future estimating and planning.

In addition, iPAS was designed generically, thus it can be widely used for different industry such as manufacture, education, medicine, construction and rail industries, etc. The report formats can also be customised according to the requirements from specific users.

Next chapter will discuss and reviews the experimental results of applying the PBIS framework together with iPAS in a case study.

Chapter 6. Case Studies and Evaluation

Results

The PBIS framework and the project management tool iPAS have been discussed in last three chapters. This chapter is to introduce two case studies that applied PBIS framework and its techniques with assist of using iPAS tool in Company A (the real company in case study is a military related engineering and manufacturing company, so no real company name is provided in this thesis due to data sensitive issue) and National Physical Laboratory (NPL) to assess its suitability in these contexts. The intention of the case studies is to test the applicability and the usability of this new framework. Engineering and manufacturing domain and scientific research domain based case studies have been adopted in this thesis for the following reasons: 1) it represents a typical domain where the tailoring of project management is heavily influenced by the user experience; 2) the engineering, manufacturing and scientific research sector are heavily investing on IT systems such as project management systems to assist project planning and monitoring; 3) the demand for benchmarking project information provision is increasing as users continue to request for the best practices to support effective information sharing.

The case studies will validate the PBIS framework from both the perspectives of identifying user needs for project information sharing and the techniques of PBIS framework. Along with PBIS framework being considered as the primary candidate, other theoretical framework including product benchmarking and recommendation method would also be examined. Evaluations would be done through project data analysis performance judgement by experienced project managers and experts for real projects.

6.1 Case Study One

6.1.1 Background

Company A was formed just after the Second World War to provide engineering solutions for governments and commercial customers, both in the United Kingdom and overseas. The Company embraces comprehensive logistic support services, engineering design, development, manufacturing and installation. Company A's core business activities include

Systems Engineering, Whole Life Support, Manufacturing, and Asset Management/Health Monitoring Systems.

In last decade, the company spends a great deal of time bidding for projects from the Ministry of Defence (MOD). Each project plan and costing was developed from scratch, even when elements of projects are similar to those bid for in the past. This takes considerable time and therefore incurs resource costs which could be a bid cost saving. It also means that bids are not always consistent and sometimes contain inaccuracies which can be costly if the project is won and the cost profile is proved to be wrong. On contract award it is difficult to substantiate existing data on project success to improve customer confidence. Moreover, customer like MOD often only allows 30 days to prepare and submit technical and financial proposals. Accordingly, firms should be armed with as much knowledge as possible in advance, and proposal management must be efficiently organised to ensure a high-quality submission is produced in short period of time.

Therefore there is an increasing demand from Company A to have a system to identify through project life cost of Engineering Solutions division, and integrate existing project management data with new project management systems to ensure data can be compared across the entire history of projects during invitation to tender and on contract award. Especially the Engineering Solutions division is committed to use leading edge technology, which leads them to frequently experiments with new technology.

Company A didn't have a formal software engineering process or a formal project management method in place before this research. Projects were conducted and managed in an ad-hoc manner. The emphasis was on delivering as much high quality engineering systems as possible with the resources available, with minimal management overhead. Most engineering and manufacturing projects were initiated by discussing needs with the users on a regular basis. Users expressed their desired features and delivery dates. Support engineers assessed the difficulty of developing these features and estimated to the best of their knowledge when the features could be delivered. Objectives were then assigned to resources, without preparing a detailed project plan or effort estimates. In addition, these projects were driven by deadlines and features to be delivered, thus actual effort was not tracked. During a project, the project manager evaluated progress by ad-hoc discussions with the resources. Delivery dates were estimated using expert judgement.

This measurement of project progression was not very precise either in the company; it was quite subjective and often leads to late discovery of schedule slippage, making it also difficult

to assess the impact of changes to user requirements and resource allocation. The difficulty to make realistic commitments was an important issue for the Engineering Solutions division in Company A. It was this issue that led Engineering Solutions division to try a more systematic approach to conduct its projects.

In this case, PBIS was introduced to help Company A to increase the company confidence in the accuracy at ITT (Invitation to Tender) responses and improve the project management process, as well as justify through life costs and plan resources to serve contracts. The case study aimed to apply the new project information sharing method in real industry scenarios using actual data from the Company A.

6.1.2 Application of PBIS Framework

In this section, a ten-month project PSE (Psychological Support Element) in Company A will be introduced to employ the PBIS framework during its project management life cycle. Due to PSE project was contracted with MOD, the information of this project is confidential; some detailed information will not be described in this thesis.

Originally the bidding proposal of PSE project for Invitation To Tender (ITT) has been made from scratch and the project was successfully contracted with Company A started from 2015. There were some problems discovered by the end of the first stage of the project. For example, due to the project proposal was created and integrated by three groups (Integrated Logistic Services, Engineering solution and Safety and Health) of Company A within one month time, there was no consistent quote validation mechanism for most deliverables and lacking of a general control of the quality of the project plan, thus the bidding cost and time in one group was well estimated but in another two groups was poorly estimated, the total real cost of the project was over £78,000 after stage one. The main reason of the wrong estimation is because insufficient attention paid to the Company A Engineering solution by ILS, many details were missed before submitting ITT response even they have been used for similar project before.

When the second stage was just about commencing two years ago, the PBIS framework was developed and iPAS system was ready for use, consequently Company A decided to take the opportunity to use this new approach to assistant project managers to manage the project in parallel of existing project management method in the company. Before applying PBIS framework, project teams in Company A has managed to input the data (e.g. deliverables with

efforts made) of some repeated or related projects in the history into the iPAS data repository as required.

6.1.2.1 Product Based Breakdown

According to the PBIS framework, the first step is to understand and articulate the user requirements from the ITT and then use the articulated information to break project into detailed product based units. As mentioned in Chapter 2, all the deliverables of a project and the component parts can be seen as products. A product may be a tangible one such as a document, piece of software, an engineering component or it may be an intangible such as culture change or change in work process.

ITT has an important documentation - Statement of Work (SOW). SOW is a formal document that captures and defines the work activities, deliverables and timeline a vendor will execute against in performance of specified work for the customer. Detailed requirements and pricing are usually included in the SOW, along with standard regulatory and governance terms and conditions.

The areas that are addressed by the SOW in PSE cover the scope of the work which describes exact nature of the work to be done, location of work which describes where the work is to be performed, allowable time for projects, deliverables schedule, industry specific standards applied, what objective criteria will be used to state the work is acceptable and special requirements which specifies any special hardware or software, and anything else not covered in the contract specifics. **Figure 6-1** presents one of the required deliverables - 19” shock Protected Enclosures specified in the SOW document. The detailed description of the each sub products underneath 19” Shock Protected Enclosures are provided together with the given working order. **Figure 6-2** illustrates the partial customer requirements to the operational environment and acceptance criteria.

SECTION 3 - TECHNICAL SPECIFICATION FOR 19" SHOCK PROTECTED ENCLOSURES

3.1 General Construction

3.1.1 Terminal Case

3.1.1.1 The Terminal Case will be 12U high (615mm) x 534mm wide x 800mm deep with two 63mm deep lids. The front lid will have an aperture for fitting of an indicator panel and air vent. The rear lid will have an aperture for fitting of a connector panel complete with air vent and fans.

3.1.1.2 The quantity of this case required against this procurement specification is 6 off.

3.1.1.3 Commence soon after Workstation Case and Processor Case are completed

3.1.2 Processor Case

3.1.2.1 The Processor Case will be 10U high (526mm) x 534mm wide x 800mm deep with two 63mm deep lids. The front lid will have an aperture for fitting of an air vent. The rear lid will have an aperture for fitting of a connector panel complete with air vent and fans.

3.1.2.2 The quantity of this case required against this procurement specification is 6 off.

3.1.2.3 Commence soon after Workstation Case is completed

3.1.3 Workstation Case

3.1.3.1 The Workstation Case will be 6U high (348mm) x 534mm wide x 800mm deep with two 63mm deep lids. The front lid will have an aperture for fitting of an air vent. The rear lid will have an aperture for fitting of a connector panel complete with air vent and fans.

3.1.3.2 The quantity of this case required against this procurement specification is 24 off.

3.2 Physical dimensions and weight

3.2.1 The enclosure dimensions shall be as the attached drawings at Annex A

3.2.2 The mass of each enclosure shall be kept to a minimum where practicable.

3.3 Installed Equipment Weights

3.3.1 The total mass of the installed items in each case are shown on the attached drawings at Annex A.

Figure 6-1: SOW Example for PSE Project – Deliverable Specification

3.4 Environmental

3.4.1 The system and therefore the 19" enclosures shall:

- a) Be subjected to and survive
- b) Provide protection to the installed equipment against
- c) Operate in the following environmental conditions:

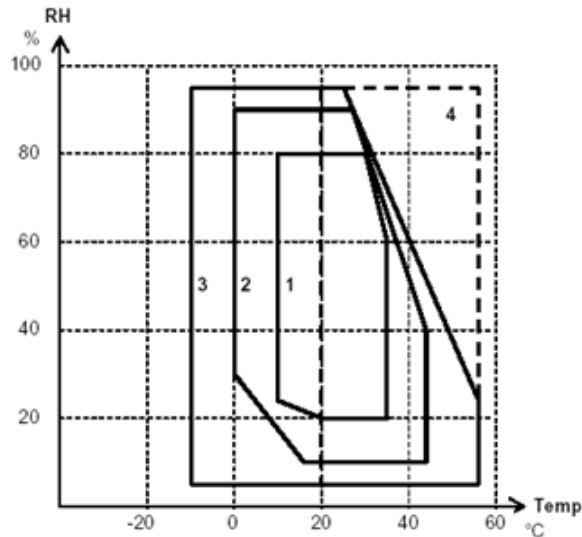


Figure 5. Temperature and humidity conditions

3.4.2 The system shall not suffer damage when operated under the conditions given by area 3 in figure 5, tested according to IEC 60068-2-1 [ref21], test Ab/Ad.

3.4.3 The system shall not suffer damage when operated under the conditions given by area 3 in figure 5, tested according to IEC 60068-2-2 [ref 22], test Bb/Bd.

Figure 6-2: SOW Exmample for PSE Project – System Requirements

During the stage of requirements articulation from ITT, many efforts have been made to analyse SOW and a lot of work were carried out with experienced project managers in Company A to identify the necessary deliverables of this project in as much detail as possible based on product based planning technique – PBS, PD and PFD were generated respectively. Product refinement rules discussed in section 3.2.3 were applied to validate the breaking down products.

The **Figure 6-3** demonstrates the breaking down the required products of PSE project. The PBS has offered a clear, exhaustive and hierarchical structure of all deliverables of PSE project. It is important to note that products may be physical or conceptual e.g. ILS deliverable grouping, hazard log, safety and health plan.

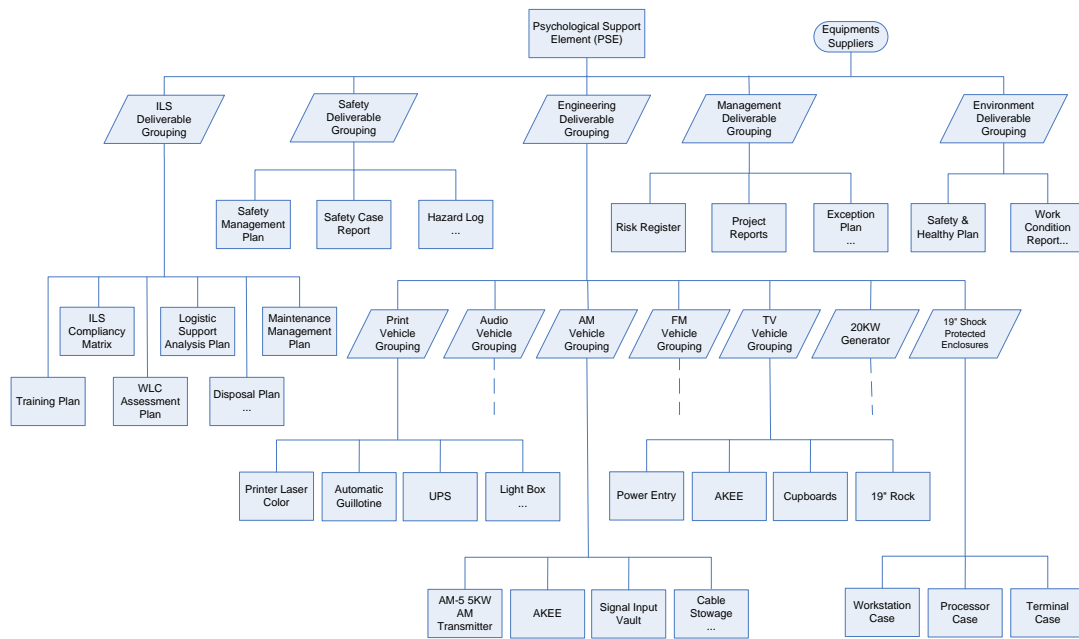


Figure 6-3: PSE Project - Product Break Structure

From PBS diagram above, PSE project was divided into five super deliverable groups: ILS, Safety, Engineering, Management and Environment. Each of the super groups might be further broken down to some small deliverable groups such as Print, Audio, AM, FM and TV groups under Engineering super deliverable group, or detailed products if there is no more group needed underneath.

According to the SOW, the Compliance Matrix is the first deliverable of the project, then Logistic Support Analysis Plan and Whole Life Cycle Assessment Plan, etc. illustrated in **Figure 6-4**. After the Disposal Plan of ILS is delivered, Safety Management Plan will be implemented afterwards, other deliverables from other delivery groups will also be implemented in the meantime. Please note, the Equipment Suppliers provide necessary equipment or devices supply to most of the sub-products in the project but it's identified as an external product since project manager have no control on it.

Take the product 19" shock Protected Enclosures as example, the sub product Workstation Case needs to be delivered firstly, then Processor Case to be delivered, the last sub product Terminal Case commences only after both Workstation Case and Processor Case are completed. This working order information were used to fill the dependences and pre-requisites attributes of the product portfolio, and also used to create PFD.

The information such as deliverable descriptions, and system requirements and acceptance criteria in SOW were entered into iPAS system as different properties of the product based portfolios.

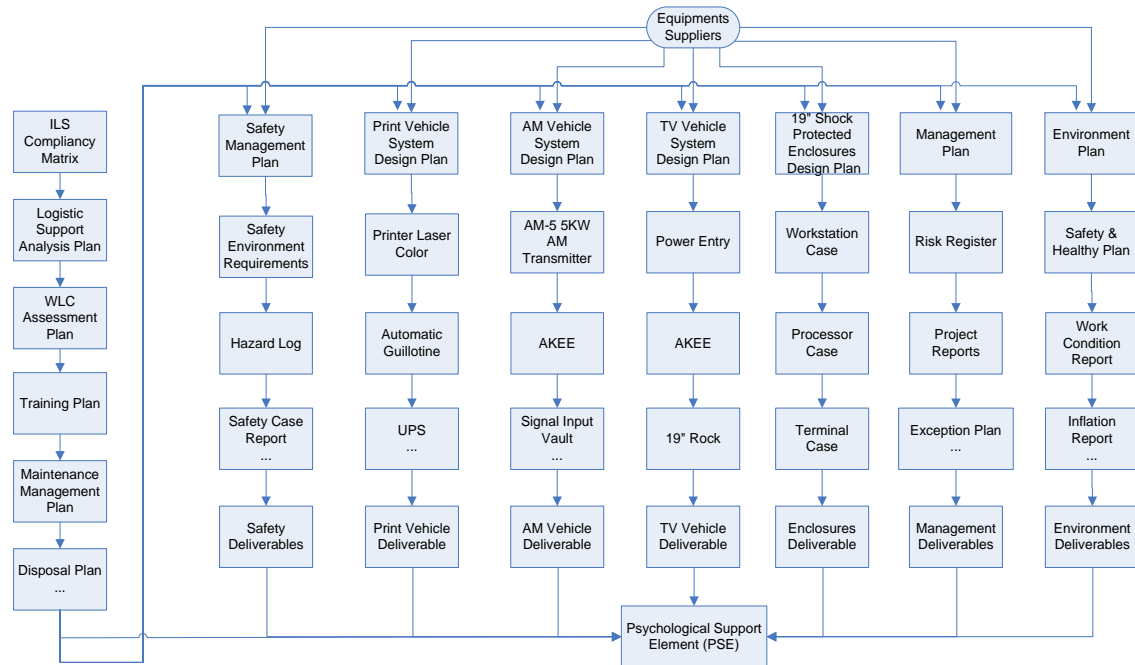


Figure 6-4: PSE Project - Product Flow Diagram

6.1.2.2 Project Planning and Monitoring

A. Project Planning

After breaking the final product into sub-products and stored as product based portfolios, the next step is to enter project general information and settings as shown in **Figure 6-5** and employ product benchmarking and recommendation engine to look into the sub-product portfolios and find the best practice among the historical data for project planning. In order to do so, project performance criteria need to be set up beforehand. According to the SOW document, the PSE project delivery time is very crucial to the customer, the project completion date was fixed, thus project *Time* chosen as the higher Project Plan Build Priority of the project in iPAS. In another word, the project completion *Time* is prior to *Cost* during the benchmarking process (shown as in **Figure 6-6**). In terms of the experience of the project managers, the Criteria Expectation of project completion *Time* and project completion *Cost* were both set as Upper Quartile, which means all the sub-products defined in PSE project will be benchmarked according to the chosen two criteria, the products in the ranges that meet

both the criteria will be regarded as the best practice results for further recommendation and qualification.

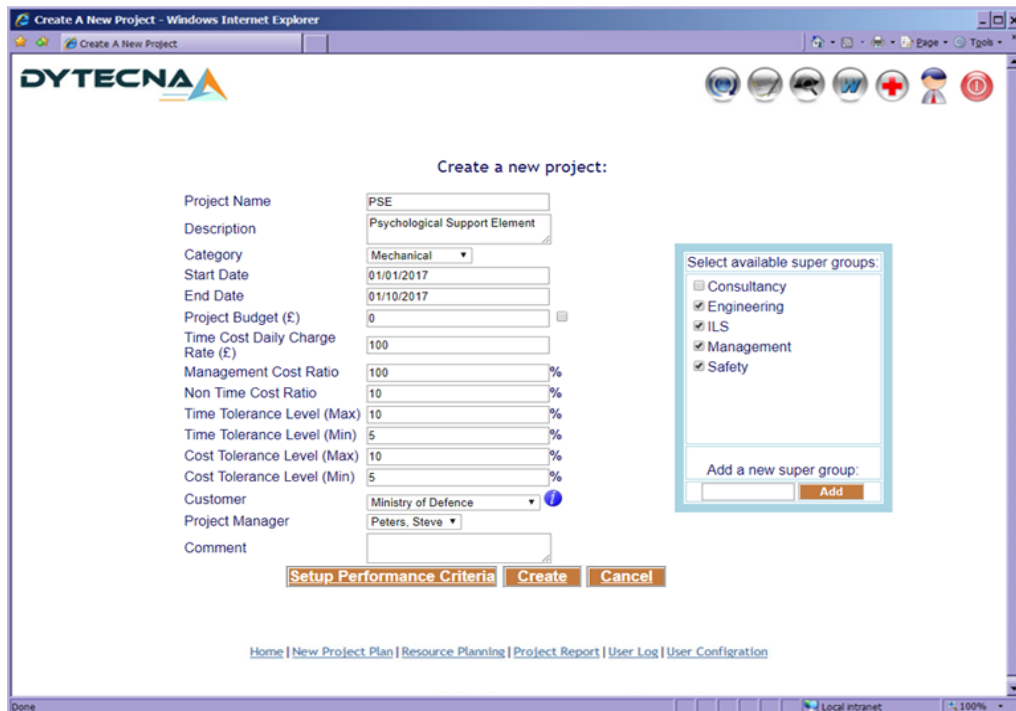


Figure 6-5: Create A New Project Page

Figure 6-6 presents the configuration page for project performance benchmarking criteria.

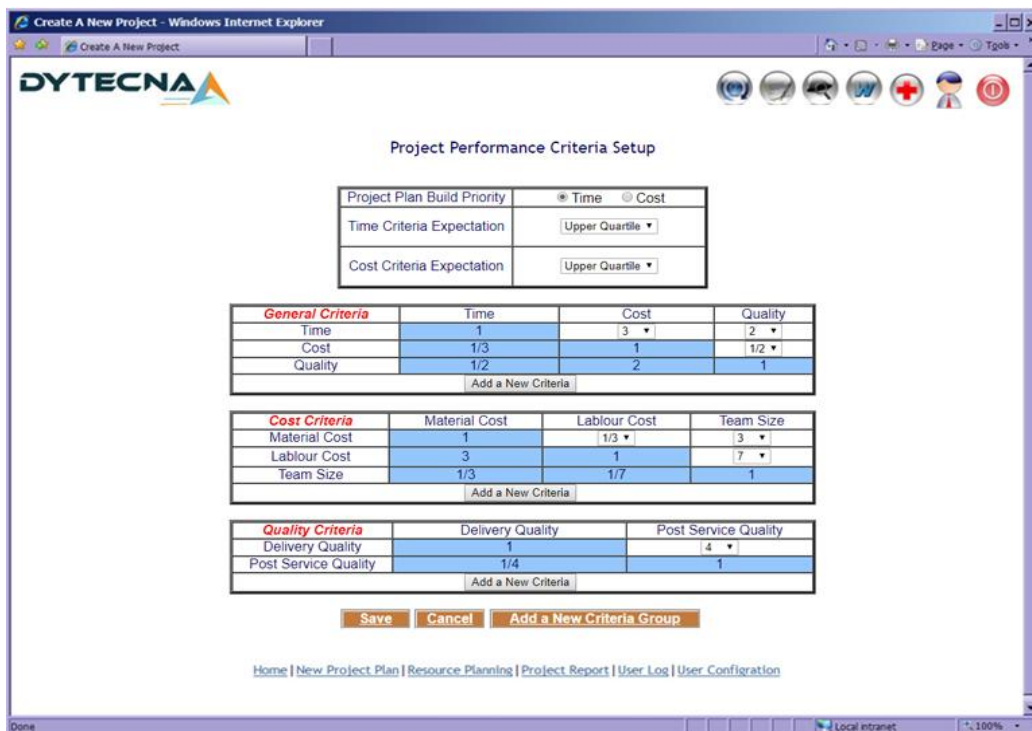


Figure 6-6: Setup Project Performance Criteria

Also on the Project Performance Criteria Setup page shown as **Figure 6-6**, a set of performance measures was derived from the Criteria Generator component discussed in section 4.1 need to be configured. Each criterion was assigned with significant attribute against others in the different criteria group by PSE project team based on **Table 4-13**. In General Criteria group, *Time* was set moderately important (3) over *Cost*; also *Cost* was set equally to moderately important (2) over *Quality*. *Quality* was set equally to moderately important (2) than *Cost*. In Cost Criteria Group, *Labour Cost* was set moderately important (3) over *Material Cost*; also *Material Cost* was set moderately important (3) over *Team Size*. *Labour Cost* was set very strong important (7) than *Team Size*. In Quantity Criteria group, *Delivery* was set moderately to strongly importance (4) over *Post Service*. After performance measures configured and saved, the product benchmarking and recommendation engine in iPAS will perform mathematical calculations to convert these judgments to priorities for each of the criterion in different group.

Next a product “Terminal Case” selected from project PSE will be used as an example to demonstrate the product benchmarking and recommendation process of product portfolio. **Table 6-1** illustrates the portfolio of one of the completed “Terminal Case” products.

Table 6-1: Example of Product Portfolio

Example of Product Portfolio - Terminal Case	
Product name and description	Terminal Case - 12U high (615mm) x 534mm wide x 800mm deep with two 63mm deep lids. The front lid will have an aperture for fitting of an indicator panel and air vent. The rear lid will have an aperture for fitting of a connector panel complete with air vent and fans. Quantity required: 6
Star Date	23/10/2015
End Date	25/10/2015
Man power	2 person
Cost (labour and material)	£4100
Prerequisites or dependency	Commence soon after Workstation Case and Processor Case are completed
Activities	<ol style="list-style-type: none"> 1) Drill apertures in the front and rear lid 2) Fit a connector panel 3) Fit air vents and fans 4) Final test 5) Quality insurance test
Quality assessment criteria	To meet industry standard MIL-STD-461E
Quality score of delivery	95%
Quality score of post service	98%
Special technique requirements	Mechanical and safety knowledge
Constrains and risks	<ol style="list-style-type: none"> 1) The installed equipment does not represent any hazards when testing, however it is an electrical system and

	<p>appropriate care should be taken.</p> <p>2) The weight of each of the completed cases weighs in excess of 35Kg and therefore represents a manual handling risk.</p>
Lessons learned and comments	<p>1) All external faces shall be painted but the paint colour specification was not provided in time thus the work was delayed</p> <p>2) Allow sufficient time in the schedule for contractor a change out. If there is a shift in contractors, consider the time and cost it takes for a smooth handover.</p>

The product portfolio above presents the product details and relevant attributes include the product name, description, work started date and ended date, spent cost, prerequisites, activities carried out, quality assessment criteria and assessment scores, special requirements and constrains and risks, which provides a lots of information after this products has been delivered. These information will used for product benchmarking and recommendation.

iPAS system has been developed to achieve the goals of the PBIS framework in this research. The main techniques and mechanisms such as product based planning, portfolio management, product benchmark and recommendation mechanism in PBIS framework are transformed to respective system functions in iPAS such as project planning, project monitoring and project reporting. It is able to automatically deliver project plans to match the user requirements and also provides a mechanism for continuous monitoring of project execution via benchmarking and generation of project reports. Therefore, after project team entering the configuration information and setting up performance criteria (**Figure 6-6**), all the algorithm calculations and data processes will be performed by iPAS system.

There were a few hundred products named as “Terminal Case” stored in PPBP repository. Through the automated processes of product benchmarking and recommendation mechanism, a recommended product “Terminal Case” was worked out by the system. Together with the portfolio details such as activities, dependencies and constrains obtained from an identified product from data repository, all these information were used to create a new product portfolio for “Terminal Case” in new PSE project. As long as all simple products in the PSE project are found as the same or similar to the previous completed products, the product benchmarking and recommendation mechanism can be employed to choose most suitable products. The activities associated with the chosen product are regarded as the most suitable practices to deliver that product in the new PSE project plan. Actual information collected during PSE project delivery were stored into the PBPP system to cross check the accuracy of the previous planning to improve the calculation method for future references.

Figure 6-7 illustrates the web interface that processes the benchmarking and recommendation for a particular product (e.g. the “Terminal Case” product described in **Table 6-1** in this case) or a group of products if the user wants to create a project plan manually. It provides a facility to let user select available products from historical projects (the left hand side tree view) and generate the benchmarked and recommended product(s) information into a new project (the right hand side tree view) automatically. An individual product or multiple products from a group or super group can be “copied” through this mechanism of product benchmarking and recommendation which processed by the system in the run time. Finally, after all available products from previous completed projects were selected and commit for plan generation, iPAS produced a new project plan with providing estimated completion time, estimated cost and Gantt charts. The project team then reviewed this plan and manually made some modifications for special considerations such as adding new products, removing unnecessary products and editing the statistics of the effort before the ITT bidding was commit. A revised project Gantt chart was generated as shown in **Figure 6-8**. The minimum duration (within the red circle) is the critical path of the project plan, in which is the shortest project completion time in theory based on the best practise in the past. This revised project plan has been submitted to project board for consideration and approval. It helped Company A to bid the PSE project successfully.

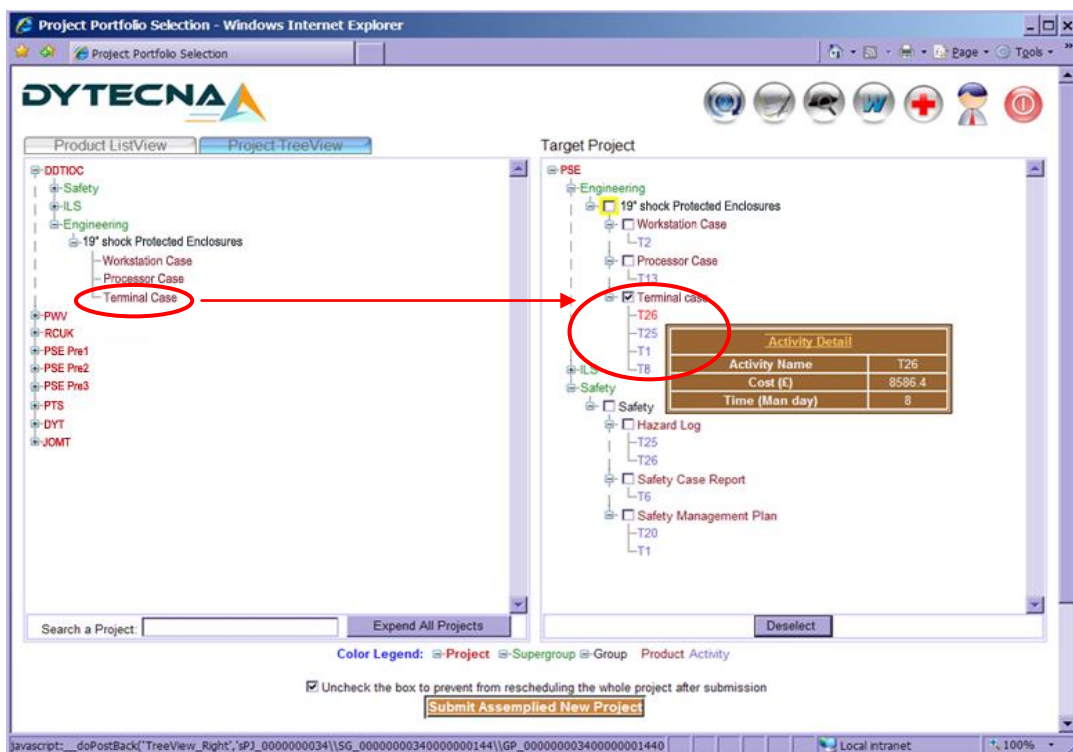


Figure 6-7: Project Portfolio Selection Page

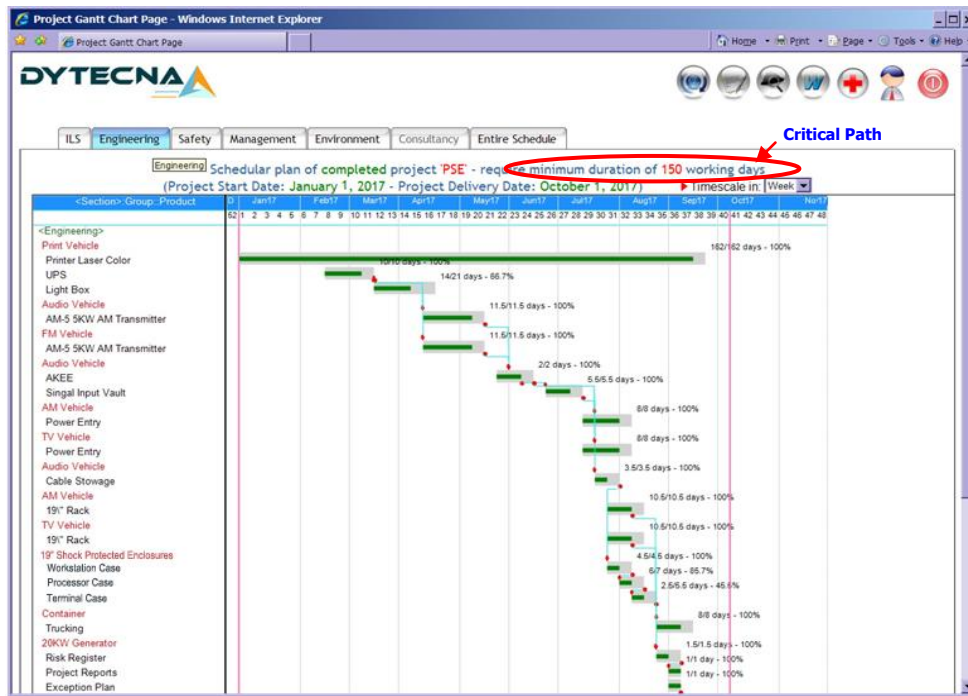


Figure 6-8: Project Plan with Gantt Chart

B. Project Monitoring

PBIS framework was also utilised with iPAS system for PSE project during its project life cycle including monitoring and delivering stages. **Figure 6-8** also shows the progresses of individual product deliverables in PSE. The left column represents a list of delivered products and the right column represents the Gantt chart plan. The green progress bars present the Earned Values of time performance against the baseline plan (grey bars), they provide a summary of effective decision making for project manager or senior project management team to take pro-active management action during the project progress. Each progress bar is associated with sub-product on the left hand side, thus it's very easy to find the product progress through the colour of the progress bar: if the colour is green means the progress is under control, time is under or on schedule and cost is under or on the budget, if the colour is red means there is a problem of the product delivery progress, project manager needs to pay attention on it and certain of actions may need to be taken in order to bring the progress back to the right track. From the diagram, it can be seen the PSE project was going quite well and most of the product were completed on time and under iPAS planned budget in its second project stage.

Moreover, there are some light blue arrows shown in the Gantt chart that represent the dependencies between products. User is able to click the each progress bar to find out more detailed information of this product (as shown in **Figure 6-9**), which including progress status,

activities, responsible person of each activity, predecessors and so on. Team leader who is responsible for the product or project manager will have authority to monitor and update the work progress of it. Team leader also is able to click the Gantt chart in product page to look up the details of each activity and amend the information such as reallocate human resources and tick the completion box when activity is completed. The activity page is shown in **Figure 6-10**.

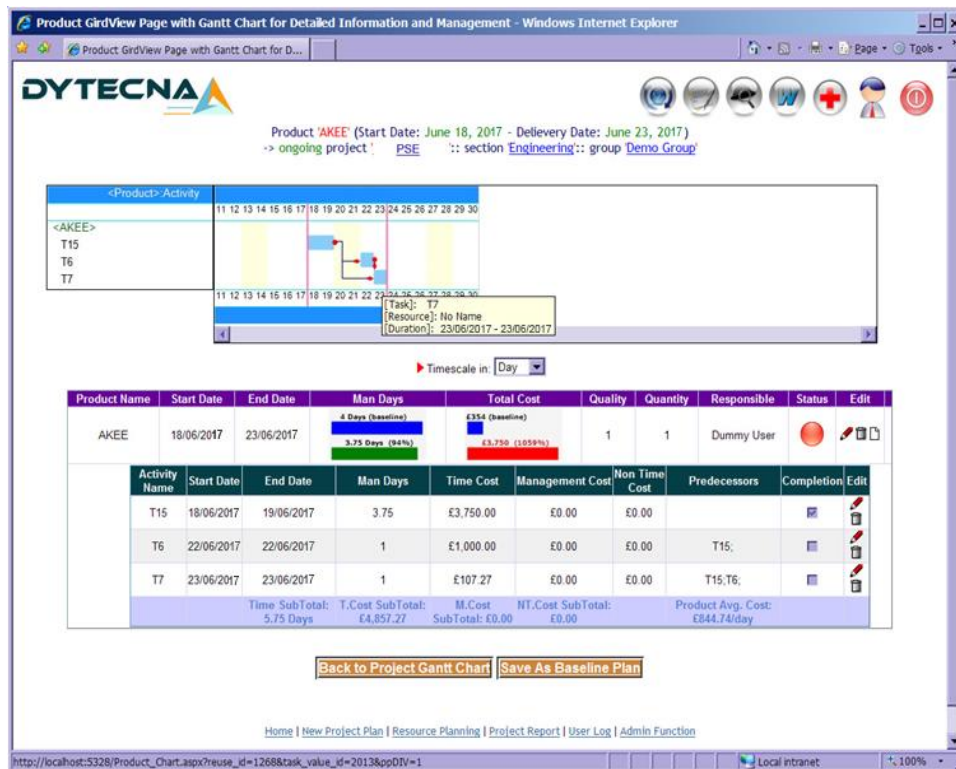


Figure 6-9: Product Detail Page

During the project, there were some monthly project reports and product benchmark reports generated through iPAS software to assist project manager to check the whole project performance regularly. **Figure 6-11** illustrates the project monthly report on spent Time and Cost compared with the project baseline which was saved after the project plan was generated first time. **Figure 6-12** illustrates the report of product “AKEE” on the actual spent Time and Cost bases.

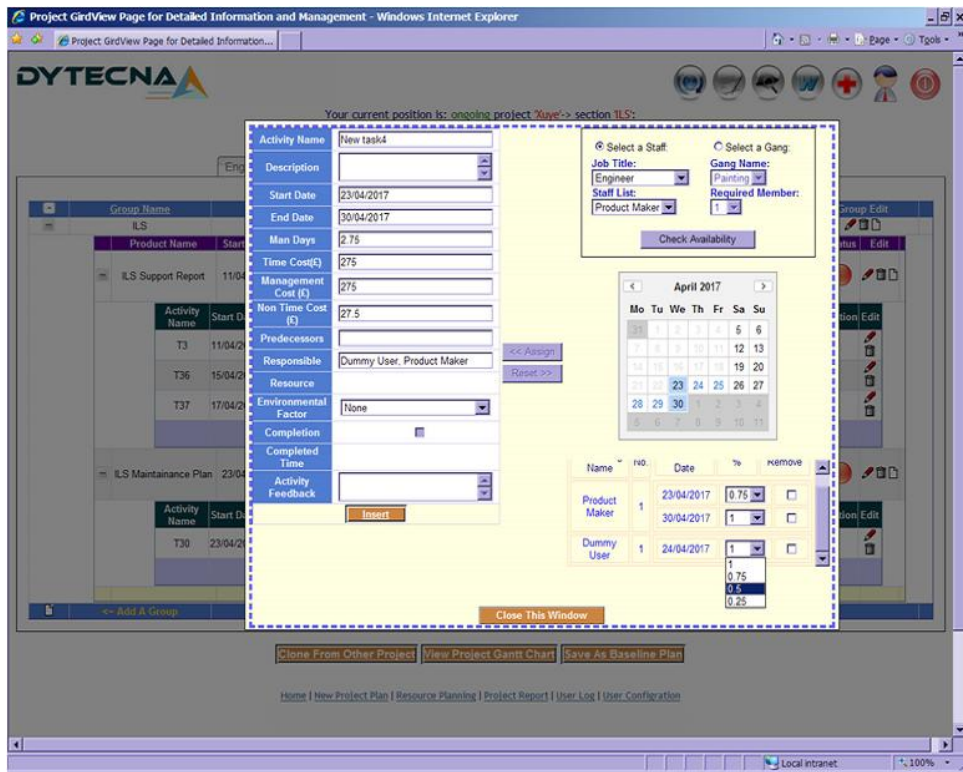


Figure 6-10: Activity Detail Page

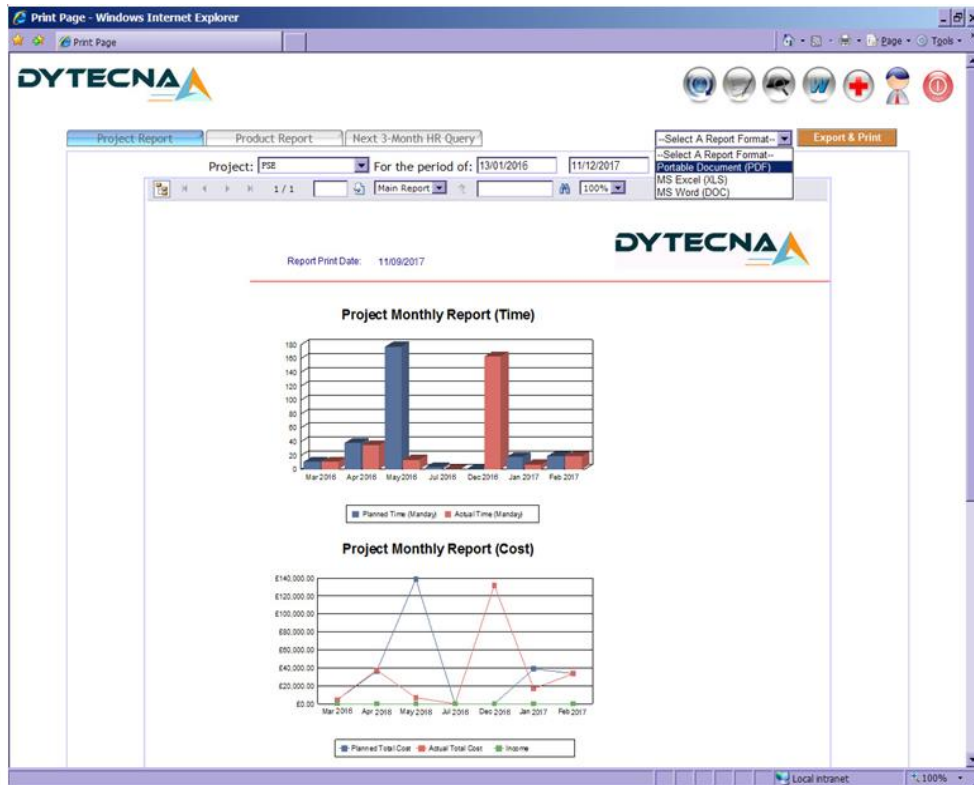


Figure 6-11: Project Monthly Report

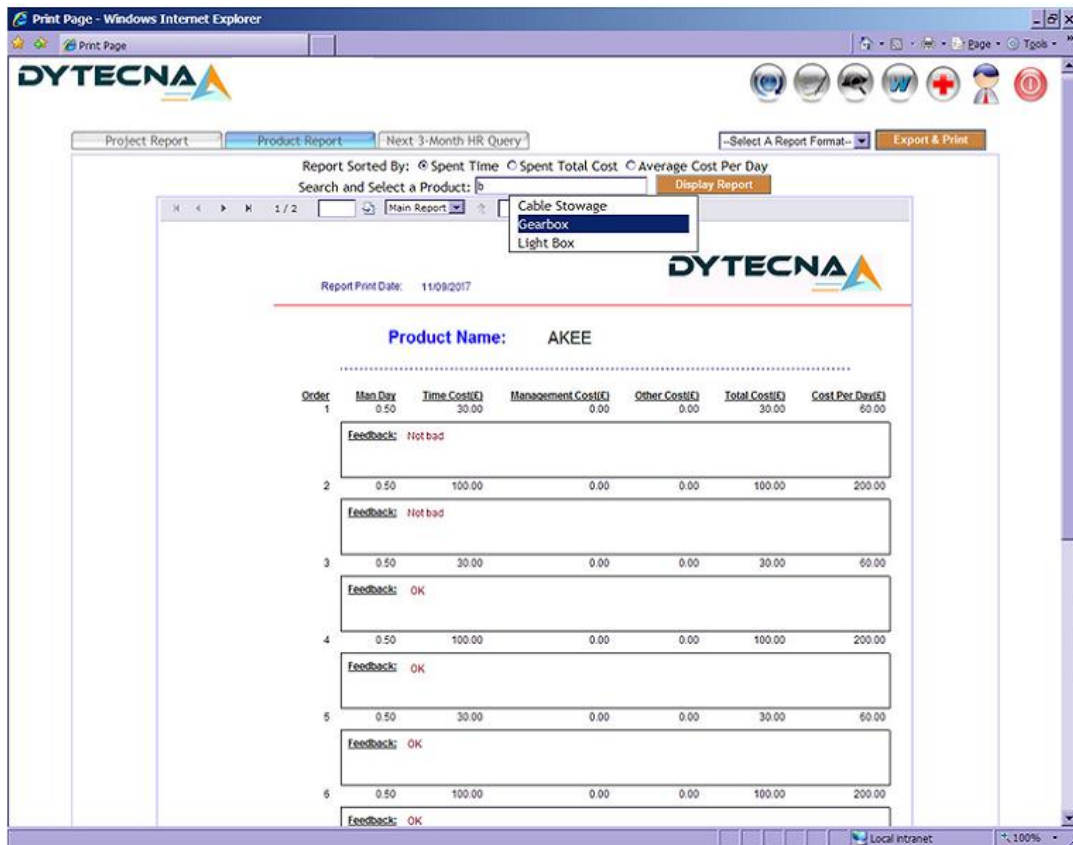


Figure 6-12: Product Report

Major benefits were observed right from the case study above, where a project was set under control and transformed into a success by researching the goals which established at the creation of the product based project plan. At the project planning stage, apart from the project manager and half of the project management team producing project plan by employing PBP technique and iPAS system, another half of the team produced another project plan as a backup plan in parallel by using original project management method in Company A. Their project management processes were still activity based exercises by using Microsoft Project and Excel (Microsoft®, 2016). After the PSE project won the contract from MOD, the whole project team worked together by using iPAS system to control and monitor the project progress till it's completed. Since Company A benefited from the efficiency and accuracy of project plan generation by using PBIS and iPAS, the new method was also introduced to two later started projects FCAC and JMOT, which won the project biddings as well via the project plan generated by using PBIS and iPAS. To ensure the planning practises more secure and less risk, there was another project team producing a backup plan in parallel as they did for PSE project.

6.2 Case Study Two

PBIS framework has also been trailed in a couple of projects in National Physical Laboratory (NPL), which followed the PRINCE principles in the organisation. Although NPL followed PRINCE in principles, the project programme officer and project managers were still using activity based approach to plan and manage projects on their favours. It was lacking a formal light weighted framework as guidance and a proper management tool to implement PRINCE2 principles before this research. Projects in NPL were still conducted and managed in an ad-hoc manner. Project managers planned the project on Gantt chart, estimate the cost pretty much relied on their personal knowledge. There are more than six hundreds staff on site or on the fields, thus to allocate staff resources to relevant projects was an impossible job if there was no accurate staff allocation details on hand. Consequently, many projects were over time or over budget due to the poor planning strategies applied. There were also some resource conflicts among projects because the staff resource could be double booked or overloaded even before projects started, this caused a lot of troubles during the project management as well.

By chance, a NPL project programme officer knew PBIS framework and iPAS system through a conference and expressed his interest in this research work. After some meetings, workshops and trainings provided by author, the NPL programme officer decided to introduce PBIS framework with iPAS system to two small scientific projects as pilot projects. Because they were pilot project, the programme officer took the same strategies that Company A has used, he assigned two project teams working in parallel at the project planning stage in order to evaluate which method was more efficient to produce the project plan, and which project plan was more accurate and able to make more profits at the end. Before introducing PBIS framework to NPL, project teams has selected and analysed some repeated or related research projects in the history based on PRINCE2 principles, then entered the data (e.g. deliverables with efforts made) into the iPAS data repository version stored in NPL as required.

According to the PBIS framework, the project team in NPL firstly understood and articulated the requirements from the Project Brief which that defines the work deliverables and timeline against in performance expectations of specified work. The project team then used the articulated information to break project into detailed product based units by following the product based planning technique, and produced PBS, PD and PFD respectively. After breaking the final product into sub-products and stored as product based portfolios, project team entered project general information and configured the performance criteria settings.

Different to Company A, the project budget was crucial than delivery time in the two pilot projects according to customer requirements, as the project budget was fixed. Thus project *Cost* chosen as the higher Project Plan Build Priority of the project in iPAS. In another word, the project *Cost* is prior to delivery *Time* during the benchmarking process. Also a set of project performance criteria were assigned with significant attribute against others in the different criteria group as well in lights of the experience of project team. After performance measures configured, iPAS performed mathematical calculations to convert these judgments to priorities for each of the criterion in different criteria groups. Project team then selected available products from historical projects and triggered the benchmarking and recommendation mechanism in iPAS to generate a new project plan with Gantt charts and estimated cost, estimated completion time automatically. Finally the project team manually added, edited and removed some products with resources and efforts through iPAS after reviewing the plan for final approval. During the project progress, iPAS also provided a good monitoring and alerting mechanism to help project teams to deal with some control and contingency issues in time.

Both pilot projects were running successfully till completion. Regretfully, this thesis is not going to include the detailed project management information for these applications due to the confidential issue, but some of the general data were collected and used for evaluation purpose in next section.

From the results observed from the two pilot projects, PBIS and iPAS have successfully assisted projects teams in NPL to plan the projects in a manageable timeframe, and monitor the project progress with providing the timely needed alters from start to end. In addition, iPAS provided a data connection between project resource allocation with staff leave and holiday sources in NPL, it's a one stop solution to reduce the resource confliction issue during the project planning stage. Therefor there were only a few resource conflicts found during the projects' progresses of the two pilot projects, it's mainly caused by the overloaded staff resource in other projects without using PBIS in NPL at that time. The project teams were very delight to use PBIS with iPAS which provided them a better approach to capture, store and sharing project information in a systematic way. During the case studies, the PBIS framework were successfully applied to help project team to share the project information for generating project plan and controlling project progresses via product based benchmarking and recommendation mechanism built in iPAS.

6.3 Evaluations and Results

This section will review and evaluate the interdisciplinary research work carried out for the requirements driven information sharing in project management.

The development of the PBIS framework was conducted by mainly adopting a qualitative methodology because of the process of developing the PBIS framework is through extensive reviews of relevant literature in the area of benchmarking and recommendation criteria selection from user requirements elicitation, product based breakdown techniques and project information sharing. The findings from the reviews reinforce that the articulation of product breakdown and planning is essential for the provision of project information sharing to support effective project management.

The proposed PBIS framework in this thesis is to assist project managers to generate a project plan which aims to give an estimation of resource costs based on customer requirements and business context through analysing, sharing and reusing data collected from previous completed projects. The PBIS framework has adopted project management and knowledge management paradigms which provide an insight on product based project portfolio management and product benchmarking and recommendation mechanism for information sharing. The evaluation of the PBIS framework has been emphasised on its usability, applicability, and most importantly on the assumptions made during its development.

6.3.1 Evaluation through Case Studies

The PBIS framework has been tested and validated mainly by a few project management case studies in manufacturing industry domain and scientific research domain. In order to evaluate the research outcome, a set of project management measures are need to demined the evidence from case studies that the proposed method is advanced to others. Pennypacker (2005) suggested ten project management benchmarking measures, but selecting three to seven measures for the measurement system is recommended as it's too difficult and costly to collect too many measures. Therefore, this research selected Return on Investment (ROI), Cost Performance Index (CPI), Schedule Performance Index (SPI) and Planning Performance Index (PPI) as the project management benchmarking measures.

6.3.1.1 Evaluation Results for Company A Projects

The four measures are calculated for the completed three projects in Company A by using following appropriate formula (Roseke Bernie, Eng, 2017):

$$\text{ROI} = (\text{Project Bidding Price} - \text{Actual Spent Cost}) \times 100\% / \text{Actual Spent Cost}$$

$$\text{Project Bidding Price} = \text{Estimated Spent Cost} \times (1 + 20\%)$$

Note: 20% is the margin defined by Company A

$$\text{CPI} = \text{Earned Value} / \text{Actual Spent Cost}$$

$$\text{Earned Value} = \text{Percent Complete} \times \text{Estimated Spent Cost}$$

$$\text{SPI} = \text{Earned Value} / \text{Actual Spent Time}$$

$$\text{Earned Value} = \text{Percent Complete} \times \text{Estimated Spent Time}$$

$$\text{PPI} = \text{Project Planning Time} / \text{Window of Time for ITT Bidding (30 days)}$$

Interpretation of the calculation results:

- The bigger of the ROI, the better - means more profits made
- If CPI is less than 1, the project is over budget.
- If CPI is zero, the project is on budget.
- If CPI is greater than 1, the project is under budget.
- If SPI is less than 1, the project is over schedule.
- If SPI is zero, the project is on schedule.
- If SPI is greater than 1, the project is under schedule.
- PPI is less than 1, the project plan is generated for ITT bidding in time
- PPI is greater than 1, the project plan generation is failed for ITT bidding

The **Table 6-2** below demonstrates the collected relevant data from three MOD proved projects PSE, FCAC and JMOT in Company A by using two different methods - activity based planning (ABP) approach and PBIS which is product based planning (PBP) approach. example in Project name column, PSE indicates the project used ABP method at the project planning stage while PSE (PBIS) indicates the project used PBIS based method at the project planning stage.

Table 6-2: Comparison Results of Completed Projects in Company A

Project	Preparation time (day)	Planning time (day)	Review time (day)	Est. spent time (day)	Est. spent cost (£)	Actual spent time (day)	Actual spent cost (£)
PSE	3	15	5	186	386080.96	195	436455.74
PSE (PBIS)	3	5	3	201	454568.45		
FCAC	3	18	6	220	554670.50	230	594563.36
FCAC (PBIS)	3	7	4	228	582903.32		
JMOT	5	20	5	250	802350.98	240	817065.42
JMOT (PBIS)	4	7	4	243	817459.23		

The preparation time is the time spent on studying the ITT and relevant documents, and analysing historical data and lessons learned previously. The planning time is the time spent on producing the project plan for ITT bidding, and drawing the Gant chart and allocating resources. The planning review time is the time spent on reviewing the project plan and getting approval from project board before the ITT bidding submission. Estimated spent time is the estimated duration of the whole project. Estimated spent cost is the estimated cost of the whole project, includes all kinds of cost such material, labour and overhead etc. Efficiency of monitoring is the ratio of the project monitoring performed sufficiently in a convenient way by project team members. Efficiency of alert received is the ratio of the alerts received or observed by project team members when issues raised during the project progress. Actual spent time is the actual duration for completing the whole project. Actual spent cost is the actual cost of the whole project, includes all kinds of cost such material, labour, management and overhead etc.

Based on the gathering data shown in **Table 6-2**, five charts are generated below to make side by side comparisons between the traditional ABP method and PBIS which is using PBP method at the project planning stage.

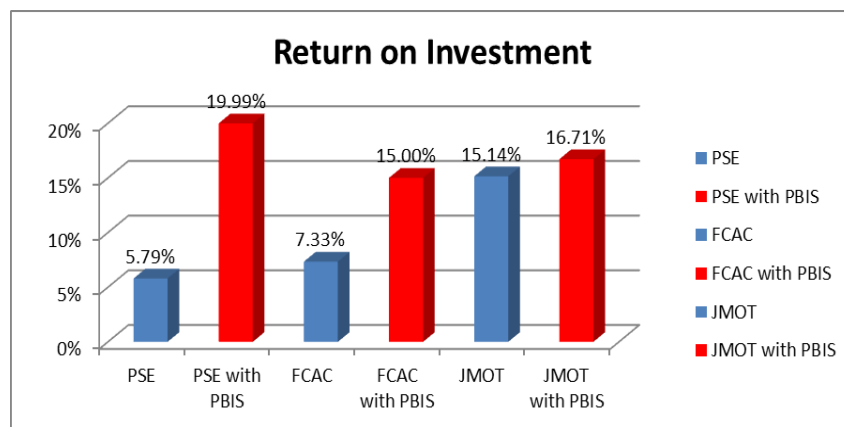


Figure 6-13: Return on Investment (ROI) Comparisons

Figure 6-13 presents the ROI comparisons between the two planning methods against three projects. With applying PBIS, the ROI value of project PSE is about three times more than the profits made by using ABP method. As to project FCAC, ROI produced by using PBIS based method is about twice as much using ABP method. Project JMOT gained a good profit by using ABP method but it's still less than the profit generated by using PBIS based method.

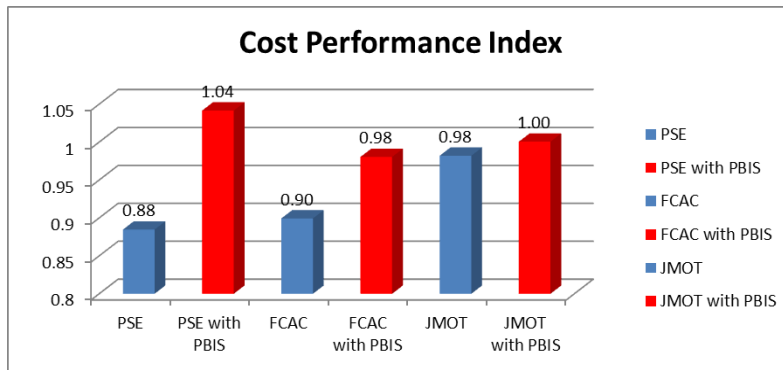


Figure 6-14: Cost Performance Index (CPI) Comparisons

Figure 6-14 presents the CPI comparisons between the two planning methods against three projects. With applying PBIS, the CPI values in project PSE and JMOT are both over 1, means the projects were under the budget, the CPI value of project FCAC is 0.98, which means it's slightly over the budget. While with using ABP, the CPI values of all three projects are under 1, means they were all over the budget although JMOT project was just slightly over the budget.

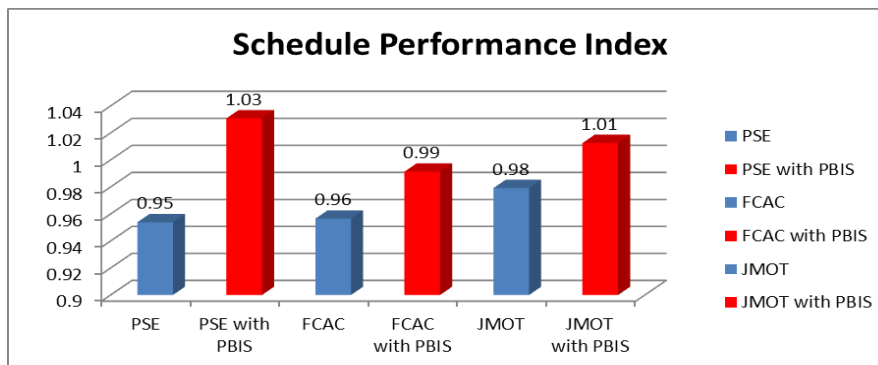


Figure 6-15: Schedule Performance Index (SPI) Comparisons

Figure 6-15 presents the SPI comparisons between the two planning methods against three projects. With applying PBIS, the SPI values in project PSE and JMOT are both over 1, means the projects were under the schedule, the SPI value of project FCAC is 0.99, which means it's just slightly over the schedule. With using ABP, the SPI values of all three projects are under 1, means they were all over schedule.

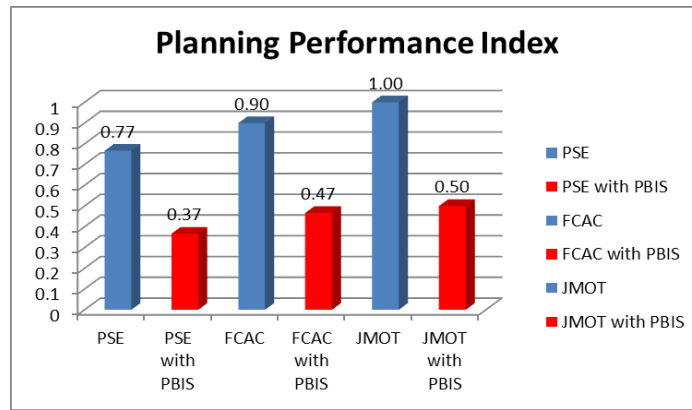


Figure 6-16: Planning Performance Index (PPI) Comparisons

Figure 6-16 presents the PPI comparisons between the two planning methods against three projects. Although the values of PPI of all projects are under 1, with applying PBIS based method the PPI values are much lower than applying ABP method, which means project plan generated by using PBIS based method took much less time than using ABP method.

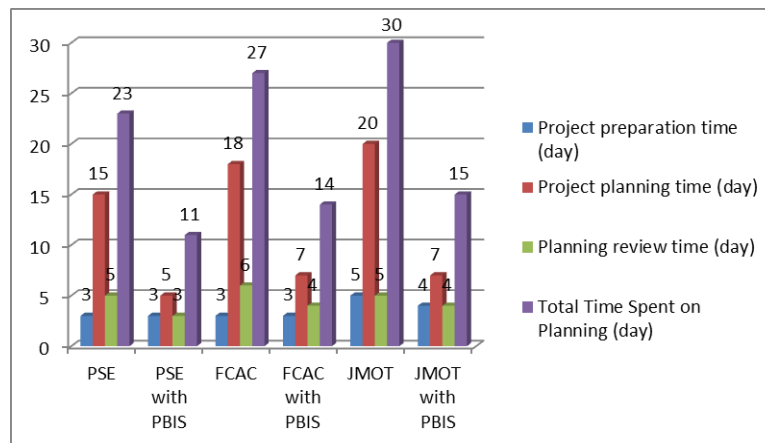


Figure 6-17: Comparisons of Spent Time on Each Project Planning Stage

Figure 6-17 compares the time spent on each project planning stage and the total time spent between the two planning methods against three projects. The results show the project team spent at least 23 days to submit a new project plan by using ABP approach even most of the products in new project are the same to previous completed projects. As MOD normally only allows 30 days window of time for a bidding submission, it's extremely stressful and time consuming for project team to work the project plan out in such short time period. With using PBIS and iPAS system, project team spent almost half of the time of ABP approach to generate and submit the plan, so the project team and project board had enough time to review and modify the plan before the final bidding submission. The only stage that spent time was close for both approaches was the project preparation stage, as both project teams must go

through the ITT document to understand the customer expectations, quality and acceptance criteria clearly, and learn the lessons from previous projects. This analysis stage took at least several days for both teams.

It is clear from the results and charts above that the project plans generated by using PBIS based method and iPAS system had huge advantages compared the plans generated using ABP method. The novel method speeds up tendering responses with accuracy and efficiency, avoids potential deliverables are missing from the plan and improves the ROI. In addition, the project team members are less stressful with the assistance from iPAS system. Customers have more confidence in bids made and associated cost profiles. Company is also able to justify through costs and plan resources to serve contracts to improve company success and profitability.

6.3.1.2 Evaluation Results for NPL Projects

The same four measures are calculated for the completed two scientific projects in NPL by using the formulas applied in section 6.2.1.1, apart from the margin is defined differently in ROI formula and the Window of Time of Plan Approval defined differently in PPI formula:

$$ROI = (\text{Project Bidding Price} - \text{Actual Spent Cost}) \times 100\% / \text{Actual Spent Cost}$$

$$\text{Project Bidding Price} = \text{Estimated Spent Cost} \times (1 + 15\%)$$

Note: 15% is the margin defined by NPL

$$PPI = \text{Project Planning Time} / \text{Window of Time for Plan Approval (28 days)}$$

The interpretation of the calculation results is the same as in section 6.2.1.1 apart from:

- PPI is less than 1, the project plan is generated for approval in time
- PPI is greater than 1, the project plan generation is failed for approval

The **Table 6-3** below demonstrates the collected relevant data from two small scientific projects in NPL by using two different methods - ABP approach and PBIS approach.

Table 6-3: Comparison Results of Completed Projects in NPL

Project	Preparation time (day)	Planning time (day)	Review time (day)	Est. spent time (day)	Est. spent cost (£)	Actual spent time (day)	Actual spent cost (£)
Project A	3	14	7	100	284367.97	112	321245.26
Project A (PBIS)	3	6	4	115	311204.66		
Project B	4	15	8	120	320356.02	130	359081.54
Project B (PBIS)	3	6	4	132	370247.98		

All the columns are defined as same as in **Table 6-2**, apart from the preparation time is defined as the time spent on studying the Project Brief instead of ITT. The planning time is

defined as the time spent on producing the project plan for approval rather than for IIT bidding submission. Based on the gathering data shown in **Table 6-3**, five charts are generated below to make side by side comparisons between the traditional ABP method and PBIS which is using PBP method at the project planning stage.

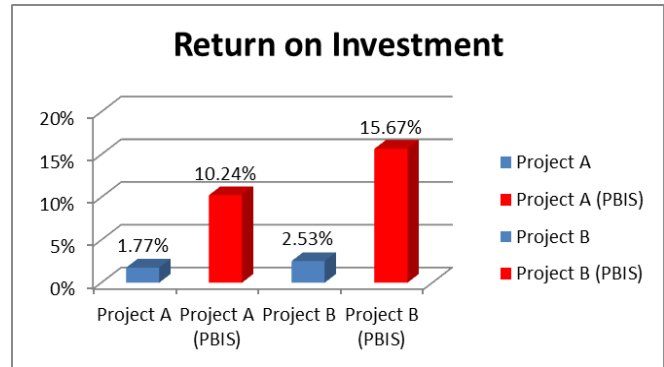


Figure 6-18: Return on Investment (ROI) Comparisons – NPL projects

Figure 6-18 presents the ROI comparisons between the two planning methods against two pilot projects. With applying PBIS, the ROIs of project A and B about five times more than the profits made by using ABP method. This results indicate PBIS and iPAS were able to produce more accurate project plans and hugely improve NPL’s profitability.

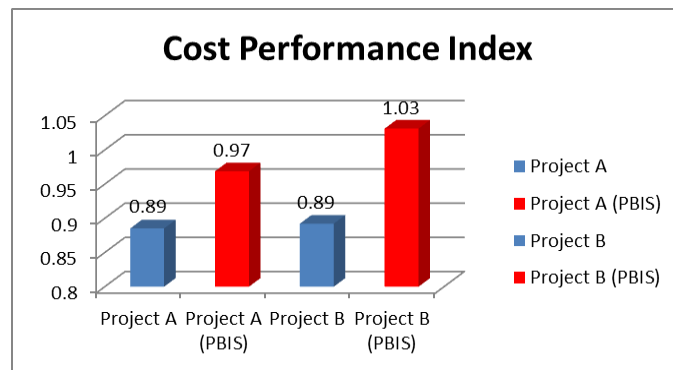


Figure 6-19: Cost Performance Index (CPI) Comparisons – NPL projects

Figure 6-19 presents the CPI comparisons between the two planning methods against two pilot projects. With applying PBIS, the CPI value in project A is over 1, means the project was under the budget, the CPI value of project B is 0.97, which means it’s slightly over the budget. While with using ABP, the CPI values of both projects are under 1, means they were all over the budget. Even compare the two CPI values in project A, the amount of over budge by using ABP method is more than using PBIS based method.

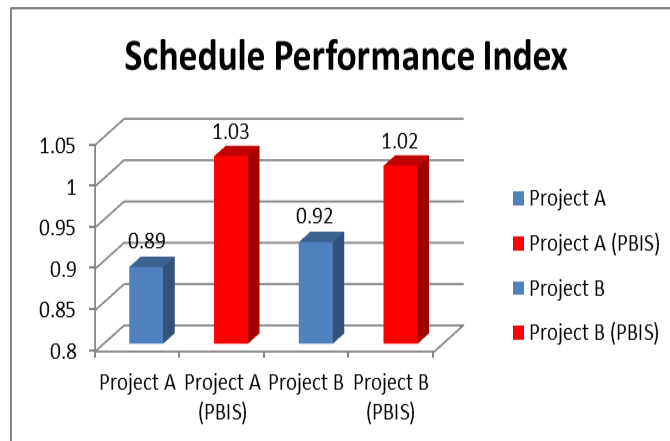


Figure 6-20: Schedule Performance Index (SPI) Comparisons – NPL projects

Figure 6-20 presents the SPI comparisons between the two planning methods against two pilot projects. With applying PBIS, the SPI values in project A and B are both over 1, means the projects were under the schedule. With using ABP, the SPI values of both projects are under 1, means they were all over schedule, although they were quite close to the deadline.

Figure 6-21 presents the PPI comparisons between the two planning methods against two pilot projects. Although the values of PPI of all projects are under 1, with applying PBIS based method the PPI values are about half of the PPI values generated by ABP method, which means project plan generated by using PBIS based method took much less time than using ABP method.

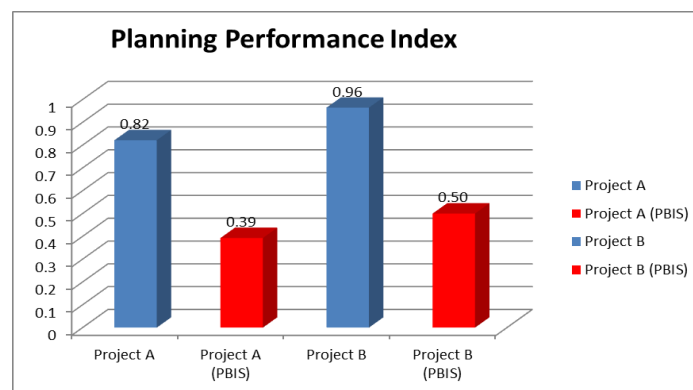


Figure 6-21: Planning Performance Index (PPI) Comparisons – NPL projects

Figure 6-22 compares the time spent on each project planning stage and the total time spent between the two planning methods. With using PBIS and iPAS system, project team spent almost half of the time by using ABP method to generate the plan, so the project team had enough time to review and modify the plan before submitting the final version for approval. The only stage that spent time (three to four days) was closed for both approaches was the

project preparation stage, which is very similar to the project statistic figures obtained in Company A.

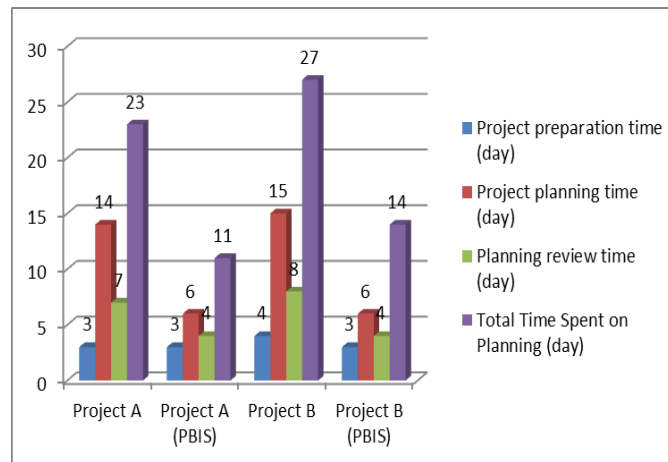


Figure 6-22: Comparisons of Spent Time on Each Project Planning Stage – NPL projects

The comparison figures of ROI, CPI, SPI and PPI above show that project plans generated by using PBIS based method and iPAS system had huge advantages compared the plans generated using ABP method, which were similar to the statistical data obtained in Company A. The PBIS framework and iPAS system helped project team to short the project planning delivery time in general with more accuracy and efficiency, and also improved NPL’s profitability through comparing and analysing the values from varying resources.

6.3.2 Evaluation through Questionnaire

So far, the PBIS framework has been evaluated quantitatively by comparing the project performance results from case studies. Next, user satisfaction of using PBIS and iPAS will be assessed through a qualitative approach. This requires a combination of conformance to requirements (the new method must produce what it would produce) and fitness for use (the system produced must satisfy the real needs). The user satisfaction comprises hard measures of user operation and soft measures of user opinions or feelings. As a result from the above, a questionnaire was designed and sent to collect the feedback from expert users through different Intranets in Company A and in NPL. The questionnaire asked eight questions about users’ general opinions after using PBIS framework and iPAS system, which can be found in **Appendix A** of this thesis.

The questionnaire examined two aspects of this research work: the first three questions measured the users’ opinion on the acceptance level of PBIS, and examined whether the introduction of the PBIS as a new project management method is successful in terms of the

project performance results and users experience in general. The second part of the questionnaire has five questions which extracted the user experience on using iPAS system mainly and collect the feedback, suggestions and comments for further system development. The first seven were closed questions, whereas the last question allows users to provide their feedback in their own words. Therefore, the questions mixed both quantitative and qualitative questions in order to capture more informative results.

The survey collected the answers from a total of 56 respondents from all levels of project management team distributed to three geographical sites in Company A and the project teams in NPL. The following section illustrates the gathering answers for each question.

Question 1: Is Product Based Information Sharing (PBIS) method easy to understand and implement?

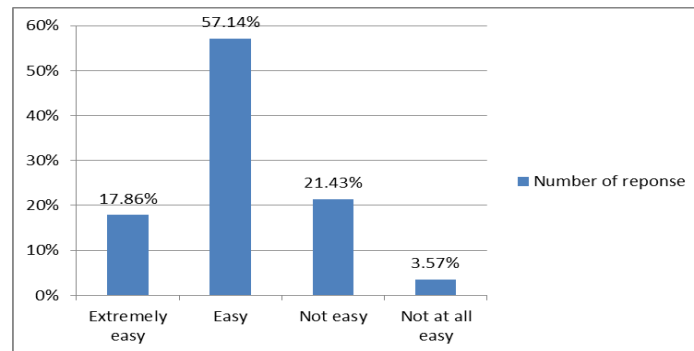


Figure 6-23: Question 1

Question 1 evaluated how users think the concept of PBIS was easily to understand and to be adapted for current project management work. From the response results, it's clear that majority of the users (75%) were quite comfortable with the introduction of PBIS, near 18% users were quite confident to use PBIS with product based planning technique because many of them have been trained through PRINCE2 courses before, and more than half of the users thought PBIS is not difficult to understand. A quarter of the users found PBIS framework was not easy or difficult to follow. Probably this was due to these users having never been trained and used PRINCE2 before or felt that activities based approach was more comfortable to take. Therefore, it can be deduced from such a positive response is that the PBIS was general well accepted by the users.

Question 2: Do you agree PBIS provides a more efficient and successful way to manage project compared with activity based project management method?

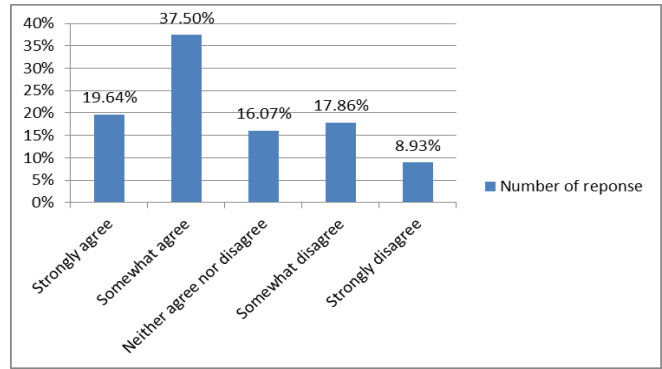


Figure 6-24: Question 2

Question 2 is mainly to measure the efficiency and success of using PBIS framework for project management compared with using use ABP method. The percentage of the respondents giving a rather positive evaluation, which is near 56% as opposed to a 27% of the user preferred ABP and 16% of the users had no bias. As all the respondents have been involved in the development of PBIS framework utilised projects, most of them had never been used product based planning technique for project planning even they have been trained. In this case, many users found it's more easy to use Microsoft Project to plan the project via activity breakdown strategy, which might negatively affect the user's choice. Still majority of the users still thought PBIS framework was more successful and efficient to assist in project management and information sharing, which it serves the original goal of this research.

Question 3: Will you use PBIS framework for project management in next project?

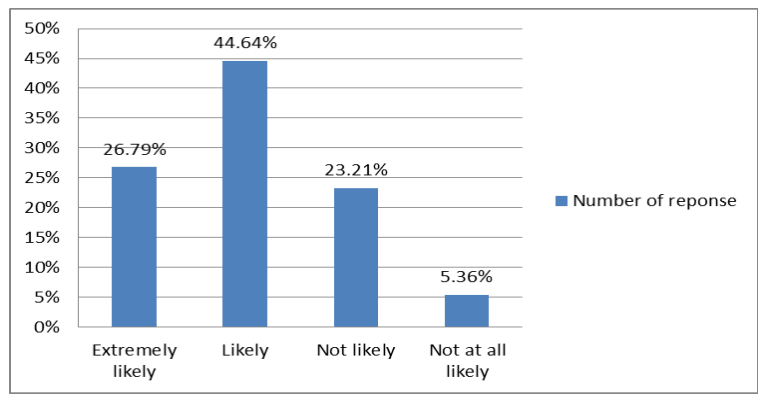


Figure 6-25: Question 3

Question 3 examined the overall confidence of the users regarding using PBIS for the future work. Despite a considerable number (29%) of users being unconfident, 71% of the users were confident or very confident by introducing PBIS framework in their next projects. This provided a strong signal that majority of the users were willing to utilise the proposed method

for their daily work, and proved that PBIS was able to improve the performance and deliverable results in real project management environments.

Question 4: How well does iPAS meet project management needs?

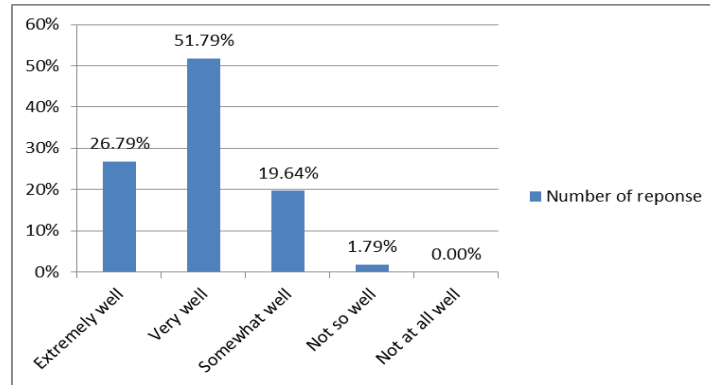


Figure 6-26: Question 4

Question 4 examined the satisfaction levels of the users regarding using iPAS as a tool to assist their project management work. The results were not surprised: about a quarter users thought iPAS was able to assist the management work extremely well, about 60% of the users quite satisfied or satisfied the functions of the tool in general. Only one user didn't think iPAS is not that helpful. This examination results were also very encouraged, which indicates iPAS as a tool was able to meet the general needs of project management and it serves the original goal of this research.

Question 5: which function(s) in iPAS you think is most useful?

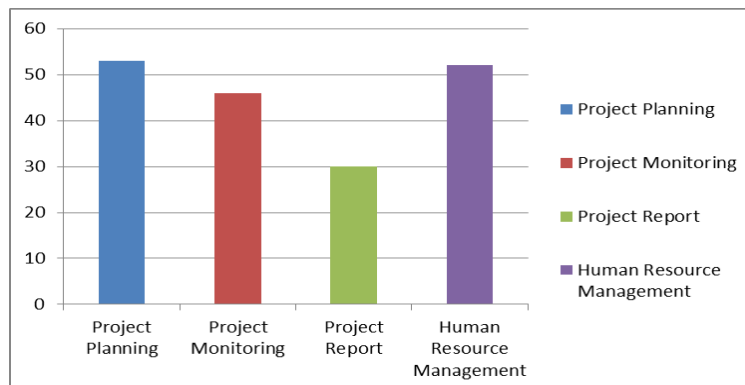


Figure 6-27: Question 5

Question 5 is a multiple answer question to examine the user preferences on system functionalities in iPAS. Most users voted “Project Planning” and “Human Resource Management” as the two most welcomed functions. This was probably because “Project Planning” function provides a certain level of automation for plan generation based on

previous project delivery and best practices thanks for the employing the product benchmarking and recommendation mechanism. And the “Human Resource Management” function was able to facilitate the human resource allocation and authentication of staff’s work absences conjunct to project planning and monitoring, which is very convenient to all project team members. The “Project Monitoring” and “Project Report” functions had fewer votes, which indicated these two functions might need further development to meet users’ expectations.

Question 6: Which of the following words would you use to describe iPAS system?

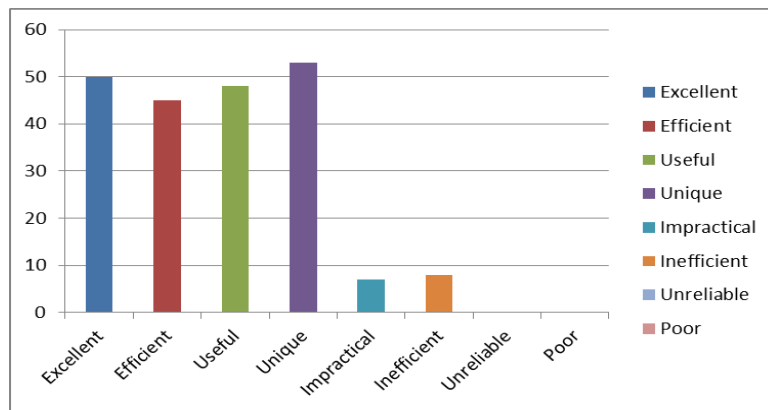


Figure 6-28: Question 6

Question 5 is also a multiple answer question to examine the user general opinion on the practical levels of iPAS system. Majority of the users considered the system were “Excellent”, “Efficient”, “Useful” and “Unique”, the votes for each of the opinion almost reached or over 50 out of 56 respondents. But there were also a few users didn’t think iPAS was practical and efficient based on their user experience, which indicated further consultancy might be required to improve the system. But in general, as new project management tool, iPAS had been recognised by majority of the users.

Question 7: Overall, how satisfied or dissatisfied are you with using PBIS framework with iPAS for project management?

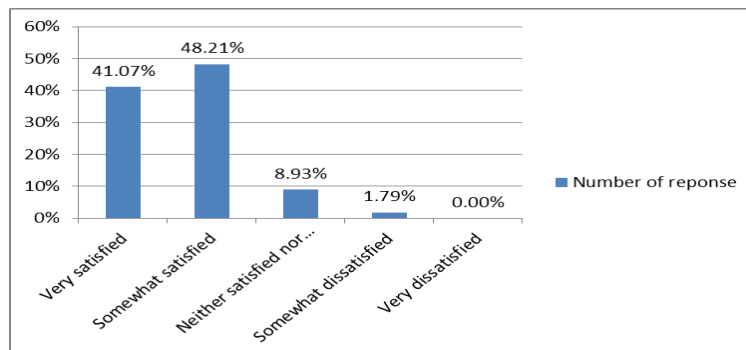


Figure 6-29: Question 7

Question 7 examined the overall satisfaction of the users regarding using PBIS framework and iPAS as a tool together for project management processes. The results were quite different with the results obtained from Question 2 and 3 which examined the PBIS framework separately. It is clear from the results that about 90% of the users were satisfied their working experience if considering PBIS and iPAS as a whole package. It probably made more sense to the users that management processes were more efficient and successful if the project management method is facilitated and supported with an efficient management tool. However, about 9% of the users still were neutral about the satisfaction and about less than 2% of the users certainly were not satisfied with the new project management method or iPAS system or both. In general, this examination results were very positive, which means PBIS and iPAS were able to satisfy majority of the users and meet the general needs of project management processes.

Question 8: Do you have any other comments or concerns about PBIS and iPAS?

The final question allowed respondents to provide any feedback, suggestions and comments regarding to PBIS framework and iPAS system. Most users put encouraged comments like “iPAS system and its functions are very impressive”, “iPAS is really handy to ‘clone’ a project and view the procuts completed in the past” and “iPAS is one of the convenient project management tools I have ever used”. Some users also raised the questions like “I like the idea of reversed planning but it’s really working practically?” and “Worry about different PM will have different views on PBS and breakdown levels, which will make the project comparison difficultly”. Some other comments mainly focus on the usability of the iPAS system. All those comments and suggestions were the motivations for future research and further system development.

6.3.3 Evaluation through Session Meetings and Workshops

During the course of this research work, domain experts such as project managers, academy researchers have been consulted and interviewed to build a thorough understanding of the problem domain. There were many regular technical meetings, project progress reviews, workshops and group assessments between the project development team and users held in vary venues, for example Company A branch sites and the National Physics Laboratory (NPL) during the development to assess the tool. As a project facilitator and researcher, author organised and attended all the session meetings and workshops. In each of the session,

author was responsible to demonstrate the software and collect the feedback from users and domain experts in order to improve the tool.

Furthermore, during the system development stage, users like project managers, programme managers, company executives and project team members had an opportunity to provide feedback, refine requirements, test the iPAS tool and view progress in focus group session meetings. In these session meetings, valuable comments and suggestions have been taken into account with regards to apply the PBIS framework for best practice sharing in project management. In addition, the project managers, engineers and technicians from the Company A, domain experts from programme managers in NPL have been involved in trailing the tool and reviewing the research outcome.

In general, users who have used the PBIS framework and iPAS system summarised the following major advantages against the traditional project management method:

- 1) It allows the company to continuously improve both bidding, planning and project management as well as reduce risk
- 2) It's a novel approach to store and share information among different projects
- 3) It's an innovative method to integrate PRINCE2 and benchmarking principles
- 4) It reduces project starting up and initiation time, reduces management costs by limiting the number of project meetings conducted
- 5) It wins more work for a customer by providing accurate rather than estimated information on costs and duration at tender stage. Thus company has more confidence in the accuracy at ITT (Invitation to Tender) responses, customers have more confidence in bids made and associated cost profiles
- 6) Company is able to justify through life costs and plan resources to serve contracts, thus to improve company success and profitability
- 7) Company has continuous improvement in data accuracy providing early identification the programmes is moving toward an adverse situation
- 8) It's adaptable to any other sectors such as construction, rail industries, healthy services or government, etc.

Table 6-3 shows the culture changes observed after the implementation of PBIS framework and using IPAS software in Company A. Before introducing PBIS framework and iPAS tool, the project plans were generated based on experts experience and probably in most case the lessons learned from previous will be easily forgotten, and the project activities were planned without clear clue because there is no a clear intention on what is going to be delivered. By

recording what was done and how much effort was spent, project team members could now easily monitor and control the project progress, accurately assess what they were doing from an objective perspective, as well as learn the lessons from the past.

Table 6-4: Culture Changes before and After Using PBIS

Stages	Pre PBIS	Post PBIS
Bidding	Ad hoc and configuration No historical data, estimation based on expert judgement No follow up, no lessons learned	Historical data are available to improve estimation Resonation and improvements of the process
Planning	Activity based planning Last minute identification of the activities	Product based planning, activities can be referred from best practice
Monitoring	Difficult to follow the evolution of a activity or to assess the quality of the completed work	Easily to monitor the progress of the project by watching the delivery quality of products and practices underneath
Control	Hard to know the failure reasons from project team level and response immediately	Failure point can be easily spot out and then take necessary action quickly

6.3.4 Compare iPAS with Other Project Management Tools

This research also analysed the functionality of iPAS compared with other project management commercial tools to make a comparison (**Table 6-5**). Some of the commercial applications have been adopted by industry at a remarkable rate (Perera *et al.*, 2017). For example, Microsoft Project (2017) is able to developing project plans with Gantt charts, assigning resources to tasks and tracking progress; MindManager (2017) can easily convert brainstorm maps into process diagrams, create standard templates so every project has continuity and can easily exported to the MS Office suite; @TASK (2017) has features such as interactive Gantt charts, calendar views and project group lists are designed to minimise downtime and make data management easy; ASTA Power Project (2017) is a standalone software to do the time planning, project progress monitoring and resource management; IBN Project Management (2017) provides a cost-effective and flexible approach to repeating success and re-using a unified system to consolidate corporate information into a single web portal.

However, the most widely used project management features of these applications are fairly conventional. For instance, the classical feature of graphical plan and critical path analysis, display the Gantt chart view by default encourages users to focus on task or activity scheduling too early, rather than identifying objectives and deliverables. Besides, plans

generated by these applications are based on tasks or activities which are difficult to do the benchmark because different project users may have different approaches to deliver a same product. In addition, due to no shared central database to store historical data, these project management applications cannot do benchmarking from previous projects and use the historical data to produce an automated project plan.

Table 6-5: Project Management Tools Comparison List

Product Criteria	iPAS	MS- Enterprise Project Manager Solution	ASTA Power Project	@TASK	IBN Project Management
Product breakdown structure	Yes	No	No	No	No
Information management	Yes	Timesheet submission	no	Yes	Yes
Organise meeting	No	Enterprise solution will automatically synchronize with team members calendars and provides lists in MS Office outlook express 2007	No	Yes	Yes
Reporting	Export to PDF, Excel and Word	Reports can be created for the project progress in particular: key Progress indicators, cost, resource data, earned value analysis	Yes, the Gantt Chart is printed along with custom graphs	Online View	Yes
MS Office integration	From report to Excel, Word	Can be integrated into the Microsoft software family	No	No	Yes
Export to other formats	Export to PDF	Can be exported to PDF if add on is loaded	No	No	Yes
Templates	Yes	Can create custom templates to provide consistency	Templates can be created	Yes	Yes
Benchmark with Previous project data	Yes	No	No	No	No
Monitor project progress	Project can be monitored by graphical indicators, also by the initial screen which displays all projects	Project can be monitored by graphical indicators	User has to type in information to get an indication of project progress	User / Manager/ Executive view	Yes
Feedback for changes in project	Yes	Can test what if scenarios and changes using multiple level un-do to reverse the latest series of commands	Can test multiple scenarios and revert back via multiple un-do's	Yes	Yes
Resource allocation	Yes	Yes	Yes	Yes	Yes
Resource tracking	Yes	Yes	Yes	Yes	Yes
Runtime Platform	Web based	Stand Alone windows Client, also with web access software	Standalone client	Web Based	Web based
Project data sharable in same or different domain	Yes	Yes	No	Yes	Yes
Database	Yes	Yes runs of Microsoft SQL database	No	No	No
User admin	Yes	Yes	No	Yes	Yes
Use of use	Easy to use once training received	Easy to use GUI very good	Easy to use	Very Easy to use	Very easy to use
Prince2 compliant	Yes	No	No	No	No

Compared with the applications above, iPAS integrates project planning activities with product based planning and automated effort estimation in light of user's criteria. This is a more sophisticated project plan method which is designed to efficiently support plan creation and adjustment online based on the practices from historical data. With this method, iPAS

offers a better guidance to project managers even programme officers, because it can help in shaping the plan and decomposing global project effort estimates into product and activity efforts, tracking project progress with alert mechanisms, ensuring that the project will meet its goals in terms of PRINCE2 main principles. iPAS also takes advantage of this fact by gathering statistics which provide assistance during project management. In general, iPAS is specifically designed for managing projects following a well-defined principle, which is typical in engineering projects (e.g. software, electrical, mechanical and construction).

iPAS also has following advanced features compared with other project management tools:

1. It applies a new principle for project management to speed up and provide confidence for tendering responses with accuracy
2. It provides novel control mechanisms to improve project management success rate
3. It provides a role base control mechanism that splits the responsibilities from project team members thus influence staff to take ownership of work by gaining individual's confidence
 - Programme officer and executives can easily obtain a general view of all running projects in the company and quickly identify the outstanding issues through system alerts
 - Project manager is able to efficiently generate a project plan from best practices pool according to customer requirements thus reduce costs in terms of liquidated damages and outsourcing costs
 - Project team leader can easily monitor the product delivery progress with associated activities
 - Project team members will be involved in the project activities that they are responsible for only
4. It's easy to accommodate data transfer from existing data source into iPAS
5. It will indicate at what point a tender price becomes loss making
6. It simplifies resource planning by automatically detecting conflicts and alerting work overloads
7. It provides intelligence and accuracy enhancing your reputation above its competitors
8. It provides managed controls with issues related to projects and it can be tailored to customer requirements
9. With self-learning coupled with information sharing, it has the capability of constant improvements of its reliability.
10. It provides an interface with other systems through Data Cube for information sharing

6.3.5 Justification for Data Analysis Techniques

The geographic location of the research project within the Company A made it possible and easier to conduct face-to-face interviews with company executives, project managers. The domain experts have been extremely supportive in providing assistance in the analysis of the problem domain and the evaluation of the method. A thorough understanding of the project management practices at the Company A was first carried out before applying the PBIS framework to the manufacturing engineering domain.

An initial PBIS framework of the application domain was produced and cross-checked against the additional information received from project managers and domain experts following the request from the researcher for initial checking. The PBIS framework has been validated in five live projects in the context of project management at an engineering and manufacturing company and a scientific research organisation. The live projects were broken into sub products based on product based planning technique, The project information were modelled in the product based portfolio and subsequently ensure that the best practice information was stored and shared based on delivery unit, during the project management process. The on-going feedback received from the users and domain experts has helped to refine the PBIS framework accordingly. This has increased confidence of the outcomes produced as a result of applying PBIS and iPAS tool in case studies.

To sum up, this study has been investigated to verify in detail various aspects of the PBIS framework and provides a complete verification of the application of the PBIS framework in project management in engineering and manufacturing industries as well as scientific research domain. During this study, a complete analysis and implementation of project management cycle based on PBIS framework has been carried out. From the experience of conducting the case studies, the applicability, effectiveness and expressiveness of the PBIS framework has been verified. The project is a success because it has met its objectives. The case study has illustrated and verified the hypothesis that product based planning, portfolio management and product benchmarking and recommendation can assist project manager to improve the efficiency of project management. It is opinion of the author that the PBIS framework can be applied easily to different application domains. The PBIS framework provides a comprehensive guide for project managers to improve the project performance in a systematic way.

6.4 Critical Review

PBIS framework has been discussed so far that best practice information can be easily shared among different projects and provided users with automated planning, monitoring, reports and human resource allocation by using developed management tool - iPAS system. The survey results, feedback and comments received show that most users were impressed and satisfied with the advanced functions after using the new method with iPAS tool. Despite all of its advances, there are still a few important aspects need to be considered.

First of all, when project management team starts to plan a new project, it's very crucial to elicit, analyse and specify user requirements. Due to time consuming, this research didn't model user requirements by identifying project stakeholders and provide a methodology to articulate requirements, instead it assumes that all project stakeholders are identified beforehand, and the project benchmarking criteria and assessment criteria are predefined based on the user requirements, while how to articulate the requirements and adopt the changes from project to project hasn't been detailed addressed in this thesis. Also as the benchmark criteria should be derived from business context and customer requirements, in some cases there will be more than three main factors to be taken into account, thus how to determine the multi-criteria in more complicated projects will be the work in next stage.

Secondly, it is well known that the differences of projects may impact the planed products in a new project, as each project has different user requirements even the deliverables could be the same, how to handle the products with modified requirements is another aspect to research in. A proper conversion mechanism needs to be established to decide the product conversation rate in a new project according to the differences of previous projects. In terms of the project triangle, time and cost are quantitative data which should be easily convertible. The quality data is not easily convertible as they are subjective, thus the actual quality information should satisfy the customer requirements and the quality acceptance criteria should also be agreed with the customer beforehand. A respective conversion mechanism needs to research in as it has not provided yet in this thesis.

Finally, although case study is a good source of data, it might be an insufficient ground for generalisation if there were only one major case was studied. It would be more preferable to have a number of case studies with different environments to illustrate further the value of product based planning and management. In this particular case study, some of the project results were even not gathered because of the confidentiality. Therefore it was not able to

show the degree of the impact to the tradition project management method based on quantitative evidence. The established theoretical framework could be applied to different design scenarios and case studies of a substantial scale in the future work.

6.5 Summary

This chapter has discussed how to utilise the PBIS framework and iPAS tool in PSE project for generating project plan and monitoring project progress. It details an example how to utilise selected techniques to break down the final product and benchmark the historic data to recommend the best practices. This chapter also evaluates the results of the case studies via difference approaches and draw a critical analysis for the research. It also illustrates the powerful features of iPAS and the advantages compared with other project management tools in the market. Next chapter will give the conclusion and future work recommendations for the research.

Chapter 7. Conclusion and Future Work

7.1 Concluding Remarks

In this thesis, we have argued the needs for sharing project information and resources from past projects as best practices to support project planning and management. Therefore, a unified supporting PBIS framework has been presented with a new product based approach to capture and reuse the project information that tackles the issue from a very different perspective. The PBIS framework solves the four questions raised in Section 1.1 are as follows:

The best practice information is the explicit knowledge need to be captured and shared through a pragmatic way to optimise the management of organisational resource. In this research, the detailed project information is captured at product level and shared between projects, such as actual duration of delivering the product and actual costs to carry out the work, quality criteria of the delivery, resources required, associated activities to deliver the product successfully, dependences and pre-requisites of producing this product, quality assessment requirements, constraints and risks associated with the product, and lessons learned from completing this product and reviews received.

The adopted product based planning technique applied in this research includes PBS, PD and PFD that breaks project into detailed products is to ensure that all necessary project products (deliverables) are identified, and the best practice information to be captured at that level during the development and completion of the project. The best practice information then can be shared and transferred for enterprises to persist in contract competition and project planning.

PBPP is utilised for presenting and sharing best practice information at product level among projects. Through PBPP, the actual delivery and maintenance information can be benchmarked and shared with other projects as long as similar products are found in PBPP.

The actual information results of the simple product from previous projects can be used as the basis for planning rather than the project manager's experience. When a new project is planned, the portfolio of previous projects and simple products can be accessed and re-organised into new projects. In addition, once the plan has been made and the product

completed, the best practice information about the product can be stored in PBPP for future use.

Sharing best practice through project portfolio is a multi-criteria decision making process. A product benchmarking and recommendation mechanism is proposed. The utilization of this approach enables the inclusion of both quantitative and qualitative factors extracted from product based portfolios in the decision process. As long as the recommended products together with their associated activities are selected from the desirable project(s) and submitted for assembling, the portfolios will be copied cross to the new project. The best practice effort (e.g. time and cost) of each activity will be calculated based on the customised benchmarking criteria and recommendation algorithms.

As the main contribution of the thesis, the novel PBIS framework provides a guideline to improve the efficiency and effectiveness of the information sharing during the project management. It allows maximum information and best practice sharing among projects at the product level. This overcomes the limitation of traditional activity based methods when sharing information at the activity level. PBIS framework is also the attempt to automate project planning processes with an information system based on previous project delivery and best practices. It brings the possibility of providing global access for any projects to share product portfolio.

The second contribution of the thesis is the product benchmarking and recommendation mechanism, which delivers reliable results to support decision making and enhance performance of project planning and monitoring.

The third contribution of the thesis is the iPAS system that achieves the goals of the PBIS framework. It can automatically deliver project plans to match customer requirements as well as provides a mechanism for continuous monitoring of project execution.

The PBIS framework includes two main parts. The first part of the framework is the Project Analyser. It provides analysed and articulated requirement information in both project and product level. The articulated information will be used to assist the product based breakdown process, which is validated by product refinement rules. This Project Analyser with its supporting modules is very important to the projects in standardised industries. Firstly, it is possible to identify all the deliverables that are required which leads to a better understanding about the work needed to be done. Also project team members are able to break down the complexity to the simplest level of understanding by using product based planning. The

simple products will be used as the basic units to carry project practise information for product based portfolio management. Through product based portfolio management, information can be shared with other projects as long as similar products are found in product based portfolio. The actual information results of the simple product from previous projects can be used as the basis for planning rather than the project manager's experience. It also overcomes the limitation of traditional activity based methods when sharing information only at the activity level, and allows maximum information and best practice sharing among projects at the product level.

The second part of the framework is the Project Planner. It enables a project plan to be generated accurately and efficiently through a novel Product Benchmarking and Recommendation mechanism. As a promise of improving information sharing, this novel mechanism is utilised in PBIS to deliver reliable results that can help to support decision making and enhance performance of project planning and monitoring. This mechanism integrated with the strengths of Quartile, Data Envelopment Analysis (DEA) and Analytic Hierarchy Process (AHP) to ensure the right products are selected based on products of which attributes are important for customer criteria during the project planning stage. Compared to the traditional, mainly active based information sharing approach which only quantitative variables are considered, the utilization of this approach enables the inclusion of both quantitative and qualitative factors extracted from product based portfolios in the decision process. This is significant to the projects where some of their performance measures are qualitative in engineering and manufacturing industries.

To demonstrate the flexibility, maintainability, portability, and reusability of PBIS framework, a project management tool iPAS has been developed to bridge the gap between PBIS main principles and its application. As another important contribution of this thesis, iPAS can intelligently support project managers in project planning, optimising business performance and project cost. In addition, the other main facilities provided by the system are: reverse planning, human resource management and profiling, project monitoring and project reporting. It also allows configurable access levels based on role and rights granted that allow users to access the various management levels and features of the solution based on their individual needs. This approach ensures that each user need only see the functionality and information necessary to perform their responsibilities, thereby making the application easier to use for all stakeholders. iPAS also provides a complete project central database, storing all project data in one location for easy access, saving time and resource. It has built in deliverables' reviews and authorisations are granted online for multi-level granularity cooperation, and progress is updated in real time to reduce the need for costly meetings and

expensive time wasting. Accessed across network or intranet, all project staff can have share real time project information, best practices and learn from previous experiences with projects, all these enable more accurate future estimating and planning. In addition, as a daily basis tool, iPAS is specifically designed for managing projects following a well-defined principle.

This thesis employed a qualitative measurement in addition to quantitative approach to evaluate and measure the PBIS framework. Two case studies of using real project data in manufacturing and engineering industries domain and scientific research domain were carried out to evaluate and measure the efficiency and success of the developed PBIS framework. The evaluations were also carried out through questionnaire, session meetings and workshops during and after PBIS introduced. Drawn the conclusions from the evaluation results, the novel PBIS framework is able to reduce effort to plan new projects and manage project portfolio and decrease estimation bias thereby reducing operational risk. It speeded up tendering responses with accuracy and efficiency, avoided potential deliverables are missing from the plan therefore improved the return on investment. In addition, customers had more confidence in bids made and associated cost profiles. It also automatically benchmarks performance against company best practices, companies were able to justify through costs and plan resources to serve contracts to improve company success and profitability. PBIS framework and its techniques with assist of using iPAS system can also be used to solve other real world problems in standardised industries such as manufacture, education, medicine, construction and rail industries etc.

7.2 Future Work

The effectiveness of the PBIS framework with two case studies have been demonstrated, and it is believed that the proposed benchmarking and recommendation mechanisms can be applied in project planning and management to improve the efficiency of the information sharing. Below some of the directions in extending the PBIS framework and its applications are discussed.

7.2.1 Construct A Method to Articulate Product Selection Criteria for Benchmarking

One of the aspects to be researched in is to articulate selection criteria for best practice benchmarking. The work will be emphasis on how to efficiently identify project stakeholders and articulating user requirements. Requirements represent a detailed breakdown of the customer's expectations for the project, as well as how the project organisation will serve

those requirements. Requirements documentation provides long-term guidance for development of the work deliverable breakdown structure and support for the customer and the project organisation as they work toward concurrence on what the project needs to achieve.

In this thesis, the module of user requirements articulation in the PBIS framework hasn't been completed. It only assumed that all project stakeholders are identified and the project benchmarking criteria are predefined beforehand, while how to articulate the requirements and adopt the changes from project to project hasn't been detailed addressed. Thus future works will be to research and identify the key performance indicators for product based benchmarking based on user requirement in more complicated projects.

One possible approach to enrich the requirements articulation module and benchmarking process through requirements analysis and criteria developed for articulating key performance indicators in project management can be derived from the Organisational Semiotic (OS) framework (Stamper *et al.*, 2000; Liu & Li, 2015). OS is based on the understanding of organisations as systems of social norms that emphasises the central role of the people, their responsibility and the organisation in the analysis and design of IT applications (Stamper *et al.*, 2004). OS is a particular branch of semiotics concerned with understanding organisations as information systems. Ontology constructed following the OS principles has embedded norms to describe the social and cultural constraints from the domain of discourse. A semiotic-based ontology, which adopts OS methods and is a lightweight ontology, can overcome the weakness of the heavyweight ontology by explicitly representing the semantics of the concepts, their relationships, as well as their temporality and constraints from the social settings. The future research work is going to adopt the Semantic Analysis Method (SAM) and the Norm Analysis Method (NAM) to construct heavyweight ontology with semantically enriched information about the users and the domain of discourse to enable a better capture of user's requirements for product based benchmarking in project management. SAM and NAM provide techniques to formalise the meanings of concepts, define ontological relationships between the concepts and analyse users' behaviours (Xu *et al.*, 2016).

The semiotic-based ontology is able to embed norms which provide rigorous control over the process of requirements articulation and specifications formulation (Liu and Salter, 2002; Liu & Li, 2015). Furthermore, the domain ontology, user ontology and product based project portfolio ontology created from SAM together with norms from NAM can facilitate the completeness, consistency, adaptability and interoperability of users' requirements specifications across various problem domains.

The OS approach is also considered as a crucial method in effectively identifying key performance indicators which are critical in benchmarking processes. As a result, it should be able to ensure that appropriate benchmarking criteria are selected with effective presentation formats based on user's needs. To be able to make such selection, a number of indicators need to be predefined to measure the successfulness of the delivery of the product. Among the indicators, different weighting for each indicator may also be applied to reflect the importance of different indicators. To sum up, the OS approach is expected to clear out ambiguities and variations that are present in the current project benchmarking methods and develop an effective and sound benchmarking method that properly articulate business criteria and customer requirements.

7.2.2 Extension of iPAS Tool

As a power tool to support PBIS framework, iPAS has been developed and evaluated by many users from different organisations. A possible extension for iPAS could be to link current standalone data repository with an organisation's host data repository. Since when iPAS collects more and more business practice data from variety of organisations, there is a need to establish an appropriate knowledge base centre. To compare business practice externally, the project management community needs a data repository of benchmarking that addresses a common set of questions that are answered by a wide number and variety of organisations for diverse projects and programmes. This should be run by an independent body. Then only would organisations be able to truly benchmark themselves against a large sub-set of projects, by size, by type, by sector and by many of the other characteristics identified. Without such a data repository, lessons for improvement remain in disorder because there are no genuinely objective measures available. An external benchmarking comparison service also could be provided in order to coordinate with the unique company database system and bring in external knowledge, which will enable the customer to manage the business more efficiently.

Moreover, in order to reuse tracking data from historical projects, one must be sure that these projects used the same definitions for deliverables and their activities. For instance, there is often confusion in software engineering about the meaning of various activities like requirements analysis, software architecture, software design, and so on. There are numerous ways of realising those using different deliverables and formats, a good norm definition will help in removing these ambiguities. A semiotic approach may be applied to define the project

requirements as well as their deliverables. The future work also can be focused on enhancing project tolerance control, data integration and strengthening the statistical ability of the system, etc.

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Appendix A – Calculations from Considering P2, P3, P4 and P5 as Focal DMUs

The following calculations are continued from the calculation in section 4.4.

Table A-1 below shows the result from considering P2 as a focal DMU which produced satisfactory result of $h_0 = 1$.

Table A-1: The results from considering P2 as a focal DMU

DMUs	Time	Material Cost	Labour Cost	Team Size	Delivery Quality	Post Service	Weighted Input	Weighted Output	Efficiency (h_0)
	Input				Output				
P1	0.9	0.83	0.9	1	1	0.8	1.13	0	0.00
P2	0.8	0.83	1	0.9	0.9	0.9	1.00	1.00	1.00
P3	1	1	0.9	0.8	0.8	1	1.25	1.11	0.89
P4	0.8	0.67	0.6	0.6	0.8	0.9	1.00	1.00	1.00
P5	0.8	0.67	0.8	0.8	0.9	0.8	1.00	0.89	0.89
Weight	1.25	0	0	0	0	1.11111			

To calculate the efficiency of unit P3, the objective function is defined as:

$$\text{Maximize efficiency } h_0 = (u_1 \times 0.8 + u_2 \times 1) / (v_1 \times 1 + v_2 \times 1 + v_3 \times 0.9 + v_4 \times 0.8)$$

which is subject to all efficiency of other units (efficiency h_0 cannot be larger than 1):

subject to the efficiency of unit P1:

$$(u_1 \times 1 + u_2 \times 0.8) / (v_1 \times 0.9 + v_2 \times 0.83 + v_3 \times 0.9 + v_4 \times 1) \leq 1$$

subject to the efficiency of unit P2:

$$(u_1 \times 0.9 + u_2 \times 0.9) / (v_1 \times 0.8 + v_2 \times 0.83 + v_3 \times 1 + v_4 \times 0.9) \leq 1$$

subject to the efficiency of unit P4:

$$(u_1 \times 0.8 + u_2 \times 0.9) / (v_1 \times 0.8 + v_2 \times 0.67 + v_3 \times 0.6 + v_4 \times 0.6) \leq 1$$

subject to the efficiency of unit P5:

$$(u_1 \times 0.9 + u_2 \times 0.8) / (v_1 \times 0.8 + v_2 \times 0.67 + v_3 \times 0.8 + v_4 \times 0.9) \leq 1$$

and non-negativity and all v_i and $u_r \geq 0$.

After equation solving, input weights are changed to $v_1 = 0.609756$, $v_2 = 0$, $v_3 = 0$, $v_4 = 0.487805$, output weights are also changed to $u_1 = 0.97561$, $u_2 = 0$ and the Maximize efficiency $h_0 = 0.78$.

Table A-2 below shows the result from considering P3 as a focal DMU which produced unsatisfactory result of $h_0 = 0.78$.

Table A-2: The results from considering P3 as a focal DMU

DMUs	Time	Material Cost	Labour Cost	Team Size	Delivery Quality	Post Service	Weighted Input	Weighted Output	Efficiency (h_0)
	Input				Output				
P1	0.9	0.83	0.9	1	1	0.8	1.04	0.98	0.94
P2	0.8	0.83	1	0.9	0.9	0.9	0.93	0.88	0.95
P3	1	1	0.9	0.8	0.8	1	1.00	0.78	0.78
P4	0.8	0.67	0.6	0.6	0.8	0.9	0.78	0.78	1.00
P5	0.8	0.67	0.8	0.8	0.9	0.8	0.88	0.88	1.00
Weight	0.609756	0	0	0.487805	0.97561	0			

To calculate the efficiency of unit P4, the objective function is defined as:

$$\text{Maximize efficiency } h_0 = (u_1 \times 0.8 + u_2 \times 0.9) / (v_1 \times 0.8 + v_2 \times 0.67 + v_3 \times 0.6 + v_4 \times 0.6)$$

which is subject to all efficiency of other units (efficiency h_0 cannot be larger than 1):

subject to the efficiency of unit P1:

$$(u_1 \times 1 + u_2 \times 0.8) / (v_1 \times 0.90 + v_2 \times 0.83 + v_3 \times 0.9 + v_4 \times 1) \leq 1$$

subject to the efficiency of unit P2:

$$(u_1 \times 0.9 + u_2 \times 0.9) / (v_1 \times 0.8 + v_2 \times 0.83 + v_3 \times 1 + v_4 \times 0.9) \leq 1$$

subject to the efficiency of unit P3:

$$(u_1 \times 0.8 + u_2 \times 1) / (v_1 \times 1 + v_2 \times 1 + v_3 \times 0.9 + v_4 \times 0.8) \leq 1$$

subject to the efficiency of unit P5:

$$(u_1 \times 0.9 + u_2 \times 0.8) / (v_1 \times 0.8 + v_2 \times 0.67 + v_3 \times 0.8 + v_4 \times 0.9) \leq 1$$

and non-negativity and all v_i and $u_r \geq 0$.

After equation solving, input weights are changed to $v_1 = 0.78125, v_2 = 0, v_3 = 0.086806, v_4 = 0.538194$, output weights are changed to $u_1 = 1.25, u_2 = 0$ and the Maximize efficiency $h_0 = 0.9$.

Table A-3 below shows the result from considering P4 as a focal DMU which produced unsatisfactory result of $h_0 = 0.90$.

Table A-3: The results from considering P4 as a focal DMU

DMUs	Time	Material Cost	Labour Cost	Team Size	Delivery Quality	Post Service	Weighted Input	Weighted Output	Efficiency (h_0)
	Input				Output				
P1	0.9	0.83	0.9	1	1	0.8	1.32	1.32	1.00
P2	0.8	0.83	1	0.9	0.9	0.9	1.20	1.13	0.94
P3	1	1	0.9	0.8	0.8	1	1.29	1.00	0.78
P4	0.8	0.67	0.6	0.6	0.8	0.9	1.00	0.90	0.90
P5	0.8	0.67	0.8	0.8	0.9	0.8	1.13	1.13	1.00
Weight	0.78125	0	0.086806	0.538194	1.25	0			

To calculate the efficiency of unit P5, the objective function is defined as:

$$\text{Maximize efficiency } h_0 = (u_1 \times 0.9 + u_2 \times 0.8) / (v_1 \times 0.8 + v_2 \times 0.67 + v_3 \times 0.8 + v_4 \times 0.9)$$

which is subject to all efficiency of other units (efficiency h_0 cannot be larger than 1):

subject to the efficiency of unit P1:

$$(u_1 \times 1 + u_2 \times 0.8) / (v_1 \times 0.90 + v_2 \times 0.83 + v_3 \times 0.9 + v_4 \times 1) \leq 1$$

subject to the efficiency of unit P2:

$$(u_1 \times 0.9 + u_2 \times 0.9) / (v_1 \times 0.8 + v_2 \times 0.83 + v_3 \times 1 + v_4 \times 0.9) \leq 1$$

subject to the efficiency of unit P3:

$$(u_1 \times 0.8 + u_2 \times 1) / (v_1 \times 1 + v_2 \times 1 + v_3 \times 0.9 + v_4 \times 0.8) \leq 1$$

subject to the efficiency of unit P4:

$$(u_1 \times 0.8 + u_2 \times 0.9) / (v_1 \times 0.8 + v_2 \times 0.67 + v_3 \times 0.6 + v_4 \times 0.6) \leq 1$$

and non-negativity and all v_i and $u_r \geq 0$.

After equation solving, input weights are changed to $v_1 = 0.694444$, $v_2 = 0$, $v_3 = 0.07716$, $v_4 = 0.478395$, output weights are changed $u_1 = 0$, $u_2 = 1.11111$ and the Maximize efficiency $h_0 = 1$.

Table A-4 below shows the result from considering P5 as a focal DMU which produced satisfactory result of $h_0 = 1$.

Table A-4: The results from considering P5 as a focal DMU

DMUs	Time	Material Cost	Labour Cost	Team Size	Delivery Quality	Post Service	Weighted Input	Weighted Output	Efficiency (h_0)
	Input				Output				
P1	0.9	0.83	0.9	1	1	0.8	1.17	1.17	1.00
P2	0.8	0.83	1	0.9	0.9	0.9	1.06	1.00	0.94
P3	1	1	0.9	0.8	0.8	1	1.15	0.89	0.78
P4	0.8	0.67	0.6	0.6	0.8	0.9	0.89	0.89	1.00
P5	0.8	0.67	0.8	0.8	0.9	0.8	1.00	1.00	1.00
Weight	0.694444	0	0.07716	0.478395	1.111111	0			

Appendix B – Evaluation Questionnaire

Question 1: Is Product Based Information Sharing (PBIS) framework easy to understand and implement for project management?

- Extremely easy
- Easy
- Not easy
- Not at all easy

Question 2: Do you agree PBIS provides a more efficient and successful way to manage project compared with activity based project management method?

- Strongly agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Strongly disagree

Question 3: Will you use PBIS framework for project management in next project?

- Extremely likely
- Likely
- Not at all likely
- Not likely

Question 4: How well does iPAS meet project management needs?

- Extremely well
- Very well
- Somewhat well
- Not so well
- Not at all well

Question 5: which function(s) in iPAS you think is most useful?

- Project Planning
- Project Monitoring
- Project Report
- Human Resource Allocation

Question 6: Which of the following words would you use to describe iPAS system?

- Excellent
- Efficient
- Useful
- Unique
- Impractical
- Inefficient

Question 7: Overall, how satisfied or dissatisfied are you with using PBIS method with iPAS for project management?

- Very satisfied
- Somewhat satisfied
- Neither satisfied nor dissatisfied
- Somewhat dissatisfied
- Very dissatisfied

Question 8: Do you have any other comments or concerns about PBIS and iPAS?

Appendix C - FORM UPR16



FORM UPR16

Research Ethics Review Checklist

Please include this completed form as an appendix to your thesis (see the Postgraduate Research Student Handbook for more information)

Postgraduate Research Student (PGRS) Information		Student ID:	600409
PGRS Name:	BIN LING		
Department:	School of Engineering	First Supervisor:	Dr. Yanyan(Linda) Yang
Start Date: <small>(or progression date for Prof Doc students)</small>	01/10/2010		
Study Mode and Route:	Part-time <input checked="" type="checkbox"/>	MPhil <input type="checkbox"/>	MD <input type="checkbox"/>
	Full-time <input type="checkbox"/>	PhD <input checked="" type="checkbox"/>	Professional Doctorate <input type="checkbox"/>
Title of Thesis:	Product based information sharing in project management		
Thesis Word Count: <small>(excluding ancillary data)</small>	52946		
<p>If you are unsure about any of the following, please contact the local representative on your Faculty Ethics Committee for advice. Please note that it is your responsibility to follow the University's Ethics Policy and any relevant University, academic or professional guidelines in the conduct of your study</p> <p>Although the Ethics Committee may have given your study a favourable opinion, the final responsibility for the ethical conduct of this work lies with the researcher(s).</p>			
<p>UKRIO Finished Research Checklist: <small>(If you would like to know more about the checklist, please see your Faculty or Departmental Ethics Committee rep or see the online version of the full checklist at: http://www.ukrio.org/what-we-do/code-of-practice-for-research/)</small></p>			
a) Have all of your research and findings been reported accurately, honestly and within a reasonable time frame?	YES <input checked="" type="checkbox"/>	NO <input type="checkbox"/>	
b) Have all contributions to knowledge been acknowledged?	YES <input checked="" type="checkbox"/>	NO <input type="checkbox"/>	
c) Have you complied with all agreements relating to intellectual property, publication and authorship?	YES <input checked="" type="checkbox"/>	NO <input type="checkbox"/>	
d) Has your research data been retained in a secure and accessible form and will it remain so for the required duration?	YES <input checked="" type="checkbox"/>	NO <input type="checkbox"/>	
e) Does your research comply with all legal, ethical, and contractual requirements?	YES <input checked="" type="checkbox"/>	NO <input type="checkbox"/>	
Candidate Statement:			
I have considered the ethical dimensions of the above named research project, and have successfully obtained the necessary ethical approval(s)			
Ethical review number(s) from Faculty Ethics Committee (or from NRES/SCREC):	657C-40FD-907F-C267-7F6D-40AD-C44A-B049		
If you have not submitted your work for ethical review, and/or you have answered 'No' to one or more of questions a) to e), please explain below why this is so:			
Signed (PGRS):			Date: 28/03/2018

Appendix D - Certificate of Ethics Review



Certificate of Ethics Review

Project Title:	Product based information sharing in project management
User ID:	600409
Name:	bin ling
Application Date:	29/01/2015 20:09:56

You must download your referral certificate, print a copy and keep it as a record of this review.

The FEC representative for the School of Engineering is Giles Tewkesbury

It is your responsibility to follow the University Code of Practice on Ethical Standards and any Department/School or professional guidelines in the conduct of your study including relevant guidelines regarding health and safety of researchers including the following:

- University Policy
- Safety on Geological Fieldwork

All projects involving human participants need to offer sufficient information to potential participants to enable them to make a decision. Template participant information sheets are available from the:

- Univeristy's Ethics Site (Participant information template).

It is also your responsibility to follow University guidance on Data Protection Policy:

- General guidance for all data protection issues
- University Data Protection Policy

SchoolOrDepartment: ENG

PrimaryRole: PostgraduateStudent

SupervisorName: Dr. Yanyan Yang

HumanParticipants: Yes

ParticipationBeyondAnsweringQuestionsOrInterviews: Yes

ParticipantInformationSheets: Only simple questions on the feedback of using the software system will be answered by participants, so no participant personal information needs to be filled. All participants will be informed it's anonymous

ParticipantConfidentiality: No participants' names and personal details will be collected during the course

InvolvesNHSPatientsOrStaff: No

NoConsentOrDeception: No

CollectingOrAnalysingPersonalInfoWithoutConsent: No

InvolvesUninformedOrDependents: No

DrugsPlacebosOrOtherSubstances: No

BloodOrTissueSamples: No

PainOrMildDiscomfort: No

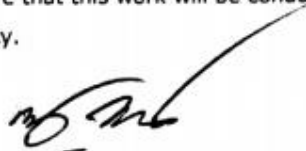
Certificate Code: 657C-40FD-907F-C267-7F6D-40AD-C44A-B049

PsychologicalStressOrAnxiety: No
ProlongedOrRepetitiveTesting: No
FinancialInducements: No
PhysicalEcologicalDamage: No
HistoricalOrCulturalDamage: No
HarmToAnimal: No
HarmfulToThirdParties: No
OutputsPotentiallyAdaptedAndMisused: No
Confirmation-ConsideredDataUse: Confirmed
Confirmation-ConsideredImpactAndMitigationOfPontentialMisuse: Confirmed
Confirmation-ActingEthicallyAndHonestly: Confirmed

Supervisor Review

As supervisor, I will ensure that this work will be conducted in an ethical manner in line with the University Ethics Policy.

Supervisor signature:



Date: 30/1/2015

Certificate Code: 657C-40FD-907F-C267-7F6D-40AD-C44A-B049