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## EARNED VALUE MANAGEMENT APPLIED TO AN ENGINEERED-TO-ORDER MULTIPLE PROJECT ENVIRONMENT

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Master of Engineering (Research)

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$31^{\text {st }}$ December 2012

## CERTIFICATE OF ORIGINALITY

I certify that the work in this thesis titled "Earned Value Management Applied to an Engineered-To-Order Multiple Project Environment" has not previously been submitted for a degree nor has it been submitted as part of the requirements for a degree except as fully acknowledged within the text. I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature of Student:

David Lincoln Fox
Date: Monday, $31^{\text {st }}$ December 2012

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## NOMENCLATURE

The content of this Nomenclature has been broken into two parts, Part A covers the acronyms relating to general text while part Part B specifically deals with the terms associated with Earned Value Management.

## Part A - General Text

ANSI American National Standards Institute
AS Australian Standards
AUD Australian Dollar
DoD (US) Department of Defense
DoE (US) Department of Energy
EIA Electronic Industries Alliance
EPCM Engineering Procurement and Construction Management
ERP Enterprise Resource Planning (software tool)
FI Final Inspection
GFC Global Financial Crisis (2008)
FAR Federal Acquisition Regulation
Host L\&A Pressure Welding Pty Ltd
IPT Independent Product Team
KPI Key Performance Indicator
LAP L\&A Pressure Welding Pty Ltd
LNG Liquefied Natural Gas
LPG Liquid Petroleum Gas
MBWA Management By Walking Around
NASA (US) National Aeronautics and Space Administration
NDIA (US) National Defence Industrial Association
N/A Not Available
OMB (US) Office of Management and Budget
OPM3 PMI's Organisational Project Management Maturity Model

| PE | (LAP) Project Engineer |
| :---: | :---: |
| PMI | Project Management Institute |
| PMS | Project Management System |
| PPM | Project Portfolio Management |
| PWHT | Post Weld Heat Treatment |
| SME | Small to Medium Enterprise |
| US | United States of America |
| wrt | 'With Respect To' |
| $\sim$ | Approximately |
| Part B1- Earned Valve Management |  |
| AC | Actual Cost |
| AD | Actual Duration |
| AT | Actual Time |
| BAC | Budget at Completion |
| CAP | Control Account Plan |
| CPI | Cost Performance Index |
| C/SCSC | Cost / Schedule Control Systems Criteria |
| CV | Cost Variance |
| EAC | Estimate at Completion |
| $\mathrm{EAC}_{\mathrm{t}}$ | Estimate at Completion (time) |
| EAC\# | Estimate at Completion (general term) |
| ED | Estimated Duration or Earned Duration, as text suggests |
| EDAC | Estimate of Duration at Completion |
| ES | Earned Schedule measure |
| ETC | Estimate to Completion |
| $\mathrm{ETC}_{\text {t }}$ | Estimate to Completion (time) |
| EV | Earned Value |


| EVM | Earned Value Management |
| :---: | :---: |
| IEAC ${ }_{\text {t }}$ | Independent Estimate at Completion (time) |
| IEAC ${ }_{\text {\# }}$ | Independent Estimate at Completion (general term) |
| IECD | Independent Estimate of the Completion Date |
| IED | Independent Estimate of (project) Duration |
| IEDAC | Independent Estimated of Duration at Completion |
| LB | Labour Budget |
| LO | Labour Only |
| LOE | Level of Effort |
| MR | Management Reserve |
| PB | Project Budget |
| PBB | Project Budget Base |
| PD | Planned Duration |
| PDWR | Planned Duration for Work Remaining |
| PERT | Project Evaluation and Review Technique |
| PF | Performance Factor |
| PMB | Performance Measurement Baseline |
| PT | Planned Time |
| PV | Planned Value |
| SAC | Schedule at Completion |
| SPI | Schedule Performance Index |
| SPIt | Schedule Performance Index (time) |
| $\mathrm{SPI}_{\#}$ | Schedule Performance Index (general term) |
| SV | Schedule Variance |
| $\mathrm{SV}_{\mathrm{t}}$ | Schedule Variance (time based) |
| TCPI | To Complete Performance index |
| TEAC | Time Estimate at Completion |
| TPB | Time Phase Budget |


| TSD | Total Scheduled Days |
| :--- | :--- |
| TSPI | To complete Schedule Performance index |
| TV | Time Variance |
| VAC | Variance at Completion |
| VAC $_{t}$ | Variance at Completion (time) |
| WBS | Work Breakdown Structure |
| WDC | Work Description Cell(s) |
| WP | Work Package |

## ABSTRACT

The supply of Engineered-to-Order pressure equipment in Australia has established a place in the global market. Local manufacturing requires innovation to maintain its position in this supply chain. Changes at the manufacturing level looked to project management to connect the end product's development and delivery with the end user's needs. Earned Value Management (EVM) offers project management a best practice in project control and its application to this niche market was considered worthy of investigation as a response to market changes.

EVM has a long history of application in large and complicated projects. This provided researchers with material to study application detail across the cost and time domains, resulting in well-established theories about performance outputs and forecasting. EVM implementation has also been the subject of research offering guidance to the user. An area of EVM that remains in the background is the application, implementation and benefits of the method in the smaller manufacturing sector. This research applies EVM to a project orientated organisation that designs and manufactures customised pressure equipment. The objective of this practice-based research is to address questions of EVM application, implementation and benefits when applied to a multiple project environment set within an operations context.

A series of twelve projects carried out by the host organisation were subject to EVM application. This provided data to assess the response of EVM to the short duration project and to explore various forecasting behaviours from both the cost and time domains under different reporting frequencies. The process of application was also used to establish qualitative information on implementation and organisational effects as a result of the methods presence.

Results indicated EVM is adaptable to the sampled manufacturing projects and tracking capabilities were positive on the few larger projects in the sample. Net benefit to the internal project management function is not represented by EVM tracking, when restricted to the short duration project. Forecasting of both cost and time was adversely affected by high material costs, but displayed stability after this project phase. Exclusion of materials
simplified application by reducing administration effort however it did exaggerate deviation of progress from the plan.

High project and organisational value is realised by access to EVM's data sources and structure. It was therefore concluded EVM methodology, coupled to organisational project management and business system theories can deliver substantial operational gains for the project orientated manufacturer.

## CHAPTER 1

## 1 Introduction

### 1.1 Background

Constructing industrial pressure equipment in Australia is a project oriented manufacturing industry that delivers custom built products to a relatively small client base. Equipment suppliers can be considered as service providers for two main sectors, being plant maintenance and new project developments. Through the decade to 2010 increased scrutiny was applied to the commercial \& engineering activities of this industry, which could best be described as a maturing of the 'project' concept for this level of the manufacturing supply chain. As this industry evolved towards a more professional approach to its projects, developments in Australian resources were intensifying, resulting in significant changes that ultimately increased supplier liability, professional service expectations and offshore competition. These changes dramatically altered the business environment for Australian pressure equipment manufacturers and for the most part can be attributed to; a move to global engineering procurement and construction management, the growth of an Asian-based manufacturing sector and the "advances in modular construction" (Cameron 2012, p. 33) being applied to Australian LNG developments. Guiding an established pressure equipment manufacturing business through this period of change required active investigation and development of business strategies to seek out innovative ways to improve the competitiveness of the Australian manufacturing brand. Addressing these issues established the need for this research project, which encompasses a micro study using the historic and current activities of a single, Sydney-based manufacturing organisation with a core business of designing and manufacturing pressure equipment for the Australian oil and gas market.

Between late 2005 and early 2007 the host organisation, a small to medium enterprise (SME) named L\&A Pressure Welding Pty Ltd (LAP) completed the largest project it had ever undertaken, involving the supply of 28 pieces of pressure equipment for the Woodside Phase V Expansion Project at Karratha in Western Australia. This project introduced the organisation to the ramping-up of client expectations and levels of scrutiny ultimately becoming a pivotal point for the company in both the way it foresaw the role of project management and its future market share of Australian-based resource fuelled projects. The 18
months that followed this project were spent developing the specific content of this research while drawing on additional experiences of other significant oil \& gas projects executed over this time line. A common theme from these experiences, which established the fundamental research question, evolved around accurately understanding and communicating; "where is the project at" and "when will it be completed".

Addressing these specific questions required the application of a project management tool. As a result this shaped the research topic towards applying Earned Value Management (EVM) to these relatively small built-to-order manufacturing projects. However addressing the changing business environment for the 'Australian manufacturer' was an equally important debate that had come to recognition by 2008. In part, the research objectives were aimed at elements of this conversation, many of which were presented in an Engineers Australia Manufacturing Discussion Paper (Engineers Australia 2008) released in the same year. So although the research concept was conceived through specific questions driven from experiences; the timing of this research had by chance, coincided with the beginning of a unique local manufacturing industry transition period and was to also be influenced by global economic change occurring at this time.

As a result of these influences, the research expanded from its initial project performance content to also investigate and combine project management theories with operational functions and business strategy development. An objective of this blending approach was to re-shape the host organisation so it could deliver on original project performance goals and also strive to add value to its end product using project management services, without changing the core business of supplying pressure equipment.

### 1.2 Literature

Research commenced solely in the realm of EVM theory. This starting gate was selected based on the goal of wanting to apply the process to projects and measure their status. Initial knowledge on the subject was limited to introductory material offered by text books such as Gray \& Larson (2003). Details here and other text related material (Smith 2008) tended to present EVM as a project management tool that offers what was considered 'a plug-in solution' to the questions frequently asked about project status. However such introductory material generally does not offer details of how the methodology is best adapted or performs relative to a project's structure. As a result more in-depth information on EVM theory was
required. It was also deemed necessary to check for existing EVM literature in the context of this research. These factors established the start criteria for an initial literature review on the topics of: 'small and medium enterprises' (SME), project management, project performance measurement and EVM application.

In sourcing information on EVM to develop a basic system the Australian Standard (AS 4817 - 2006), was initially reviewed. This document provided sufficient detail to make the necessary start, and being an Australian Standard its adoption fitted well with the industry application and a goal of maintaining alignment with (ISO 9001-2008) and other Australian standards used by LAP. Initial information gathered from this standard proved sufficient to build up a custom EVM tool and therefore allowed a temporary pause on further research in this particular area. Literature effort then turned to other topics, which seemed significant to the implementation aspects now evident if the tool is to be applied to a live work place.

Research into the topics of: SME, project management and project performance measurement identified multiple-project management as a field of study distinct from singular project management introducing the concept of 'aggregate success of multiple projects' (Fricke \& Shenhar 2000) rather than a singular project focus. This appeared to align well with the research environment introducing the idea of "an integrated project portfolio rather than a disjointed collection of projects" (Dooley, Lupton \& O'Sullivan 2005, p. 468). It was then observed that there are important differences between operational activities and project management activities and having both these elements in a single business environment creates competing interests which can produce poor results if undue precedence is given to individual functional managers, clients or projects (Maylor, Vidgen \& Carver 2008).

Material presented by these readings encouraged further research into management related fields as there was evidence that success, in general, is linked to initial planning, establishing a work environment where goals are defined, while project execution, good or bad, strengthens and develops a company's stature and management style (Stal-Le Cardinal \& Marle 2006). These ideas reinforced the developing principles that project management needs to consider the whole business using a contextual assessment strategy as a means of verifying the project fit with the business. These factors have a significant bearing on a projects identity and therefore influence how it should be organised and the type of personnel needed to make it work (Maylor, Vidgen \& Carver 2008).

Placing emphasis on project assessment, planning, context and human elements moved research into how these processes are controlled and measured. It was found uptake of existing tools varies depending on the type of project and the level of project management maturity present (Besner \& Hobbs 2008). While these traditional tools have significance at a micro level, regarding the project management approach to be applied, literature in this area also raised the concept of over-arching management tools such as 'independent product teams (IPT)' (Kim, Wells \& Duffey 2003), 'project management methodology' (Maylor, Vidgen \& Carver 2008), 'project management information system' (Raymond \& Bergeron 2008) and 'project management control system' (Kuprenas 2003). A common theme noted by this thread of literature was the focus on the human elements of project management which includes consideration of the 'project experience' for the project team (Carù, Cova \& Pace 2004).

At this point, research was shifted back to the original focus of EVM, where the mechanics of the process were again reviewed. It was evident EV in its original form had limitations in schedule prediction. Additional research exposed Earned Schedule (ES) as an alternative time measuring method (Lipke et al. 2009) to the classic EV analysis using schedule variance based on the parameters of earned value and planned value. This was a relatively new thread of literature originating in (Lipke 2003) and had significance for this research where EV is being trialled on smaller projects and where schedule (time based) indicators are of primary concern. A second pass of EVM related literature was completed after developing a suitable project management system that supported EVM application. This second round of review focused on exploring EVM characteristics, forecasting performance, alternative methods and views on the application of EVM to various project types and scenarios. Theories and developments from this more detailed second review are discussed further in Section 2.2.

The above literature summary outlines the focal areas used in the research to design a project management system that had an integrated approach with the operational aspects of the organisation. The links identified between the SME industry being examined and these newer research areas provided this research project with an opportunity to perform a genuine practice-based application study using numerous best practice theories, and to then observe and document outcomes that will assist in theory verification and enhancement.

### 1.3 Research Context

Projects investigated during this research required a combination of project and operational management theories to deliver their outcomes. This managerial mixture was present throughout the research program due to LAP's business functions being spread across both engineering services and manufacturing. The engineering functions were associated with unique project deliverables and therefore required project management, while the physical execution of each project required the application of established manufacturing processes within a factory environment and therefore required an operations management style. As a result, the context of the study and its host organisation may be characterised as a 'project orientated manufacturing organisation'.

Undertaking factory based manufacturing requires the principles of operations management to deal with production priorities, human and equipment resources as well as shop space and equipment movements. The planning and systems used to manage these cycles are quite different to projects in that they are an ongoing function that continually requires adaption to changing priorities, situations and plans. How this is coupled to the structure of a traditional engineering project and its 'plan intensive controlling format' (Cabri \& Griffiths 2006) has been an evolving process throughout the research, driven purely by the need to improve the host organisations control and data streams to support the core research outcome of EVM application. Accordingly, the experiences and outcomes of this 'theory integration' work are presented for discussion and reader review. However it is acknowledged the qualitative data generated by this part of the research has not been subject to the level of academic analysis that would normally be required if it was the main research theme across multiple samples.

The specific end product that has become the focus of this EVM application study is known as a 'pressure vessel', while the 'project' content of their construction includes activities from vessel conception through to delivery. Pressure vessels typically have a relativity simple geometry being; a cylindrical shaped vessel usually fitted with hemispherical ends, various nozzles (being pipes with flanges) protruding from the cylindrical shell and attachments (such as legs) welded to the diameter to service the vessels function and structural requirements.


Figure 1.1 - Typical Horizontal Pressure Vessel

To categorise these vessels as 'projects' within current literature, they are best described as small $^{1}$ (with unit values up to approximately $\$ 1 \mathrm{~m}$ ) 'non-innovative projects' (Besner \& Hobbs 2008), where the methods for design and construction are taken from established practices and the projects main effort is centred on manufacturing the equipment. The reason for focusing on these particular items is their simplicity and commonality in process engineering applications such as oil \& water separation for fuel processing and pressurised storage of gas. Because 'vessels' have a frequent application in oil \& gas processing, these projects make-up approximately $35 \%$ of LAP's total income and therefore are an important part of the business to develop improvements in management and product knowledge.

### 1.4 Research Focus

The typical pressure vessel project scope used in these EVM trials includes mechanical design (based on pre-defined geometry and technical aspects), creation of detailed drawings for manufacture, and the purchase of raw materials such as steel plates, pipes and flanges. After these front-end activities are completed the projects manufacturing phase occurs, consisting of forming, fabricating and welding the raw materials in accordance with the shop drawings and approved manufacture processes. Completion of the equipment involves testing the vessel's strength and compliance to manufacturing standards using a series of nondestructive testing methods. The final phase of the project is painting and delivery to the

[^0]client's plant or a construction site and the submission of quality documentation that represents the vessel's manufacturing history.

Through applying EVM to this project environment it is anticipated there will be an improved understanding of project performance, leading to other questions about how this can be measured and how this information can be used practically to improve project management for the host organisation. There is also an expectation that embedding a system of controls and feed-back across the organisations project arm will build the basis for greater product manufacturing knowledge and this should engender more effective operational management decisions. If the power of EVM can be pushed out to the wider organisation there is potential for the tool to have a significant contribution to the organisational project management function (portfolio management). Providing this vision can be delivered there is opportunity for the EVM tool to contribute beyond the traditional project specific role it is typically associated with.

Although each project is unique there are characteristics of these projects that have commonality. It is perceived that the adaption of EVM will provide data on these projects that can then be used to better understand the products manufacture cycle. Detailed manufacturing history could potentially be established from such information, leading to developing models that would represent the effort and duration required to complete these common tasks. An outcome from this; cycle analysis / model development process, is to improve knowledge in the behaviour of EVM on these small projects to the point where the tool can be used with confidence in tracking projects.

There is also opportunity to expand this modelling data into a mechanism that can simulate project manufacturing profiles, providing visual representation of time and cost relationships for these products. It is anticipated this objective could be built on the foundation that a key function of EVM is to be able to forecast project outcomes using past schedule performance (Vandevoorde \& Vanhoucke 2006). For the individual projects studied here this outcome will form part of the EVM application observation. The opportunity to achieve forecasting of a project in the definition phase by using historic EVM data and established modelling scenarios would have advantages in marketing, tendering, project assessment and risk management for the host organisation.

Being able to develop front end product assessment tools and strategies from this research would add value to the LAP product using the organisations management system \& knowledge rather than relying on the physical product to inspire innovation. Such research outcomes are well aligned with the recommendations put forward in the Engineers Australia discussion paper (2008) on Australian manufacturing and would also contribute to the company combating market pressures from lower priced imported products as recently discussed in the Sydney Morning Herald (Washington 2012a, 2012b).

### 1.5 Research Frame

To achieve enhanced product value there was an expectation the research would need to look beyond the specific projects being used for EVM testing to ensure the organisation as a whole structures itself around performance measurement and project control. In considering this broader context, the adapting of EVM to this small manufacturing project environment was always likely to pose challenges in developing a useful balance between supplying EVM's data needs, and the administrative effort required to deliver these streams within the scale of the benefit that the tool may bring to the small short-duration project. EVM heritage suggests the method evolved from large complicated government projects with a cost control focus (Kwak \& Anbari 2012), while the application being considered here is of several magnitudes smaller and has a time measuring agenda. This 'large project / cost based' ancestry has potential to present elements of EVM in a context that could be overly complicated and not a good fit to the SME application. As a result it was expected there would be considerable effort needed to understand and extract the critical elements of EVM for integration with these small projects and their context.

The other element of differentiation in this application is the manufacturing aspect and associated production functions used to deliver these projects. The archetypal large project is likely have a direct labour workforce dedicated to the project's overall objectives, however factory based (small business) manufacturing has limited labour, space and equipment resources, multiple concurrent projects and jobbing work, all of which require strategies that draw on production and operational management techniques. To achieve common organisational objectives across multiple projects, it is expected a cross discipline approach to development will benefit the outcome. Seeking out essential components of the initiation, planning phases \& linking them to management of the execution processes is likely to
converge the management strategy to a central hub controlling project and manufacturing functions.

Leaving consideration of this wider business application for the moment, EVM is a tool that initially had a singular project application, as noted originating from the large government project sector. However over time the method has been subject to much research seeking better time forecasting, simplification and wider application, all helping to improve the opportunity of using EVM in the private sector and on the smaller project environment (Anbari 2003; Fleming \& Koppelman 2006; Henderson 2003; Jacob \& Kane 2004; Kim, Wells \& Duffey 2003; Lipke 2011a). As a result, the essential ingredients and benefits of running EVM in a simplified version for the small project are reasonably well supported in literature. Fleming and Koppelman presented a short paper (Fleming \& Koppelman 2006) \& brochure (Fleming \& Koppelman 2007) identifying ten essential steps from the 32 listed in the standard ANSI/EIA 748 that represents a 'light EVM' approach. Using the work of these authors the foreseen critical elements of EVM can be explored, firstly in an isolated context using live projects to experiment with data and outcomes and then opening out into the more complex business integration goal. From this simple model EVM setup can, for this application, be reduced to; a good plan with clear scope, robust scheduling (requiring experience and product knowledge) and sound budget distribution strategies. Benefiting from this front end effort can only come to fruition if monitoring, measuring against the base line and forecasting is carried out to check performance. From this initial observation, it is assumed development will need to be done across critical EVM elements and business functions with respect to the context of the project in question and how these elements fit into the organisations day to day functional management activities. Research narrowed to these areas should provide opportunity to gain an improved understanding as to how these key elements influence EVM's overall behaviour on small projects and how the wider business activities can be integrated with these requirements.

For this research to deliver value to all its stakeholders there is a need to carry out work with two perspectives in mind; being a business case and an academic goal. It would seem natural to place emphasis on the 'academic goal'. However the host business with its ongoing project activities provides the research with the frame work in which the academic theories and application can be tried and tested. For this reason the business case, from the researcher's perspective, requires equal research effort. A notable difference occurs however in the
approach required to achieve success from the separate stakeholder perspectives. In the academic setting there is a need to build up methodology through carefully constructed research questions, which can be tested through logical analysis and reviewed to assess the rigour of the work. For the business case the measure of success is delivered through methodology uptake and tangible improvements, which will only come about if the research delivers practical solutions to problems that benefit the industry host. For this reason the work carried out under the business case has an 'applied' weighting with results presented through discussion and lessons learnt in uptake against a single research question instead of a series of formalised hypotheses setup to frame aspects of EVM application analysis which requires alignment with the academic realm.

Responding to initial research goals of using EVM to answer project status questions provides the basis for investigating this project management tool in a research environment. It is acknowledged the EVM method is a proven tracking tool well documented in academic literature, through books and a specific software market all supporting the tools use in the business community. However the question remains, are these proven theories and readily available methods equally robust when cut down to a simplified version and applied to small scale short duration manufacturing projects? From this perspective the industry setting of this research requires the development of knowledge, based on a specific type of project which also presents constraints on user input availability, all of which will be measured against practical application. Coupling these elements to the short dynamic project cycle requires investigation and testing of the method so as to deliver a level of confidence in the tool that will allow it to be implemented into a live business environment. To convincingly satisfy these business-oriented requirements, structured academic investigation is warranted and therefore requires a response to research questions in the form of a hypothesis to ensure the outcome can formulate specific recommendations that will provide industry with a proven methodology and application strategies for the project environment in question.

### 1.6 Method

### 1.6.1 System Development

The previous paragraphs introduced what are considered to be the two key elements that form the foundation of this research and the stakeholders they represent. The values, needs and constraints associated with these two groups for the most part are poles apart. Delivering results satisfactory to both of these two groups requires a method of system development that
considers their inherent values and measures of successes. Developing and introducing a new system to an SME such as LAP requires a series of steps to tease out and shape the basis of the system's objectives. It is then necessary to mesh these with existing processes to develop the boundaries of the new integrated system. Difficulties arise in implementation, brought about by balancing essential inputs needed for the new system with that of available resources. Organisational culture and conformity also contribute to challenges in delivering change management at this level.

Establishing the frame from which the research will be set, it is evident there is to be significant emphasis placed on handling business issues in this development process. As noted the research work is centred on investigating project behaviour and forecasting using EVM, so there is a vital need for good clean project data when using EVM in this way. From this it can be acknowledged the relationship between the data stream to be used and the host organisation signifies how critical the business relationship is to the research outcome.

### 1.6.2 Project Data

Project data sourced for these investigations comes from the operations of LAP and generated from new projects undertaken over the course of this research being Jan 2009 to Dec 2012. The data of interest was related to; project estimate, material purchases, direct labour hours, contracted service costs and the capture of time vs. progress. The costing structure of the organisation means project management and engineering design effort are not measured or booked as 'direct cost' therefore such effort is not included in data collection or analysis but is budgeted in the form of 'project overhead'. Nevertheless outputs from this effort do represent a portion of the 'budget at completion' in the form of engineering deliverables such as vessel drawings, calculations and quality control which are measured against their estimated value for EVM calculations (Standards Australia 2006).

The collection of data could be said to have matured as the research progressed and the value of clean data was appreciated. Initially a trial was carried out with an emphasis on using EVM, instead of capturing data as a separate process. Although this approach was useful in exploring and establishing an understanding of the mechanics behind EVM and the necessary data required to feed EVM, it was evident the research required a data focus which could then be analysed separate to managing the project. For this reason all but the first data set was collected with a data capture focus. It was also recognised that capturing normal production
activities (project durations) was important for the end goal of developing project profiles, therefore collecting data without EVM running in parallel was considered an important step in producing clean data sets for later analysis. The resulting method for data collection evolved around retaining records of hours booked to projects for each working day, transactions from accounts payable \& receivable and correlation of these figures with purchase orders, material and services received and finally daily fabrication effort captured through photographs of workshop progress.

### 1.6.3 Application Process

Data capture represents effectively half of the information stream EVM needs to function. A prerequisite to data entry is the development \& overlaying of a project schedule with a project budget. The schedule represents the project plan, listing all tasks that make up the project and sequencing them into a realistic 'activities' time line that must be completed before the projects outcome can be realised. The planning effort can be said to represent what will be the 'Earned' part of the EVM system, while the 'Value' element broadly speaking is represented by the 'Budget' when assigned to each of these planned activities. Time phasing comes from the overlaying of this schedule with the budget, whereby cost estimates are assigned across the planned activities. The combination of these time \& cost elements sets what is termed the base line for the project and represents the datum from which progress can be measured by inputting the recorded data.

EVM when set up well delivers a simple means of measuring project progress, however the ease of use is proportional to how well the setup is performed and how realistically it represents the project at hand. The method also requires a user to understand the pre-defined progress measures and it is essential that there is access to relevant data. Without these ancillary elements feeding and servicing EVM its performance will falter and useability becomes compromised.

There are three elements which are considered to be at the core of the systems operation, these being:

- Schedule development with respect to the project scope;
- Compression of this schedule and overlaying of the budget; and
- Phasing of the budget across the compressed schedule.

When discussing EVM setup these elements play a key role in adapting the system to the project environment and tailoring its level of detail.

### 1.7 Outcomes

### 1.7.1 System and Business

The reliance EVM has on data, so as to function effectively, requires the project in question to be well managed. In this particular manufacturing application the project data streams are provided through the organisation, which means the 'well managed' requirement needs to be in the context of the organisations systems rather than a particular project. Supporting this relationship influenced decisions about organisational structure and ultimately defined system outputs that would supply the necessary data feeds so the research objectives of applying EVM could be achieved. It is interesting that developing and implementing these changes in the name of research evolved into a re-structuring process that has had great influence over the organisations operational management approach. It has been observed that with each learning curve and improvement, the organisation is becoming more aware of its functional management activities and their interaction with each other. The impact of this on-going development of better understanding the business and it surroundings is also helping the organisation adapt to its changing market. While EVM was taken on board for the purpose of improving the management of projects, the wider business benefits could be said to be of greater value to this application. Through the improved control over systems, projects are in fact being managed better by the natural convergence towards a tailored project management system.

### 1.7.2 EVM Application

Application of EVM to the host organisation's processes was channelled mainly through a customised Excel Project Work Book, coupled with a Project Schedule (Gantt Chart). The Project Work Book contained specially tailored worksheets for Project Budget, Booked Hours, Materials Cost (including Services) \& Labour Allocation. Data consolidated by these worksheets were then used to create the time phase budget and reporting data needed for EVM to output project curves and forecasting data.

From the work undertaken during this research it is evident the EVM method can deliver benefit to the intended purpose of improving project management through forcing more focus on project tracking. However there is no escaping the need to supply this tool with ongoing
data, even in a cut down version. To achieve beneficial results it is necessary to have in place a practical schedule that can closely reflect a projects activities and sequences. In addition the development of a realistic budget, capturing a balanced number of activities to represent the project sufficiently is vital. Nevertheless, the budget must not be so overly detailed that it makes the consolidation of financial data difficult when applying EVM to the project. The final setup in the EVM application comes through overlaying the schedule with the budget to produce a time-phased budget. The success of this tool is dependent on the accuracy of the schedule and the detail vs. functionality balance presented by the budget. While these three elements contribute to the foundation of EVM they represent only the customised tool for the project in question and do not of themselves measure progress. To gain the benefits of this front end work, it is necessary to capture the project in data form and enter this into the customised tool. Working through all these processes requires time, which is a resource that is often lacking in an SME manufacturing organisation like LAP were individuals tend to 'wear more than one hat'. It would seem the challenges for EVM in terms of practicality, for this application, lie in minimising effort needed to prepare the customised front end.

The main lesson taken from this study indicates that the arrangement of an organisation's operational functions plays a significant role in the successful uptake of EVM. Through this frame comes better control of the process undertaken to deliver the product, and working from a tailored platform influences how well the budget and schedule, EVM's basis, can model the organisation's projects. From this the application of EVM is more manageable however there will always be the requirement to customise the setup and maintain the data feeds to achieve measurement and these inevitably add to work load. For this application the decision to run EVM, assuming methodology is established is really related to the benefit perceived by the organisation or the individual project manager. It is interesting to note that during this study the development of the supporting project systems alone considerably enhanced the management of the hosts' projects even without adding EVM to the project. However having this data on hand to feed into EVM, there is a much greater chance the tool can be utilised in these shorter duration manufacturing projects.

### 1.8 Chapter Summary

The research intention of this work was tied to an industry setting in which change in product value was required to deal with market shifts in the Australian pressure equipment manufacturing sector. The proposal was to apply Earned Value Management (EVM)
techniques to the project environment of a single Small to Medium Enterprise (SME). The host's core business is in the design and onsite manufacture of pressure equipment and is therefore at the 'coal-face' of the Australian manufacturing challenges that occurred in parallel to this research program.

The method of research involved developing a supporting project management system (PMS) sufficiently to allow EVM to be applied to a select series of projects. The projects intended for investigation focus on manufacturing pressure vessels, being the main product in the host's project portfolio. The application of EVM draws on existing organisational project scheduling practices, combining these with the necessary data streams EVM required to function. The combining of data with the schedule was to be achieved through the development of a customised EVM tool that would enable the essential time phase budget to be prepared.

The application of EVM was expected to have two outputs one relating to improving the organisational structure as a result of EVM's tight data management requirements. The other was to enhance the project management services through data feeds, reporting capabilities and forecasting tools that are EVM trademarks. These enhancements are intended to benefit internal project staff by improving their capacity to visualise project status and therefore improve decision making through access to quantitative information rather than relying on SME ownership direction. The external benefit was expected to be aligned with the ability to provide best practice project management methodology and have a capacity to more objectively report progress visually as well as through schedules and narrative formats.

## CHAPTER 2

## 2 Literature Review

### 2.1 Small Medium Enterprise

At the outset of this research it was not considered necessary to investigate the theories behind small business development, management and ownership as the focus was primarily on project management and performance measurement through earned value management application. However over the course of this research it became obvious the effects of applying academic analysis to these project orientated activities were linked back to the host organisation and its structure. As a result the research effort has had a marked effect on the business structure. In observing these changes it was recognised that elements of owner personality and business values were playing a part in the success or otherwise of the research outcomes. Based on these observations it was considered literature should be consulted regarding the attributes of small business ownership and management. The following paragraphs attempt to encapsulate concepts about Australian small business which were recognised as relevant to this research application and help to identify some of the fundamental characteristics that were observed over the period of this research project.

For the purpose of this research LAP is referred to as a Small Medium Enterprise (SME), however according to Australian classifications LAP is more precisely defined as a 'Medium Business', being a business containing between 20 and 199 employees (Australian Bureau of Statistics 2002). Nevertheless, with approximately 40 full time employees LAP is closer to the small business end of this spectrum. Characteristics of LAP's development and management history present many of the aspects discussed in literature associated with small (family) businesses. Typically, these organisations tend not to engage professional managers as this practice is often incongruent with the level of control owners may wish to exercise on the day to day running of the organisation (Graves \& Thomas 2006). This approach is also influenced by the fact that SME's are typically resource poor (Huang \& Rice 2009) therefore engaging a professional 'manager' is not financially viable in many cases. As a result there is a tendency for this type of business to have an evolutionary development path which reflects the owner's personal characteristics. Whether this is intentional or not, this outcome is common and associated with the hegemony the owner exercises through the daily interactions
they have with their employees (Kotey \& Meredith 1997). The combination of this influence coupled to managerial decision making which, under this environment, typically is a function of one or two directors rather than employees with particular skill sets (Perry, Meredith \& Cunnington 1988) results in a business system where the "owner / manager is at the centre of all enterprise behaviour" (Kotey \& Meredith 1997, p. 40). Where these characteristics dominate, particularly over long periods, it is likely the organisation will develop a 'blinkered' view of their existing product, the processes used and their market conditions. Under this scenario, there is potential for the organisation to become complacent about its status (Evans \& Sawyer 2009) resulting in innovation falling by the way-side. Innovation in this context is not necessarily associated with a product but the capacity of the business to deliver the product and adapt to technology change that introduces "disruptive innovation" to their market (Jeyaretnam 2012), which more than likely will require "a business strategy" (Kotey \& Meredith 1997, p. 38) response that is not necessarily about the organisation's end product. Where global factors are affecting manufacturers like LAP it is recognised at a national level that promoting innovation is significant in businesses surviving such external change (Engineers Australia Innovation Task Force 2012).

As this research evolved and the numerous theories reviewed began to penetrate LAP's operations it was observed that the more defined and integrated the project management system became the less pivotal the singular owner / manager strategy became in running the organisation as a whole. This was a significant, although unintentional outcome of this research, and as discussed in the opening paragraph presented an outcome for the host organisation that challenged the status quo of this family-run business and its historic "reluctance to relinquish control...and privacy" (Graves \& Thomas 2006, p. 211). In hindsight it is perhaps obvious that applying supervised project management research to a business of this nature would result in significant changes being identified. However the level of success experienced in implementing and altering the underlying systems of the business, to the extent that the locus of control was influenced, must in part be attributed to synergies between the owner's cooperative personality, the researcher's values and the roles they held in the organisation at the time of the research and also the timing of the research with respect to national \& global business activities. This fortuitous alignment of contributing elements has enabled research material to be assimilated with in-house capabilities which is proving to deliver a significant competitive advantage regarding project management services and
presents a good an example of "absorptive capacity and open innovation" concepts as presented by Huang \& Rice (2009, pp. 202-3).

In addition business outputs from this research can be aligned with developing new management and marketing methods related to product realisation through improved business processes. Such activities are associated with an element of "creativity and innovation" (Kotey \& Meredith 1997, p. 44). Successfully implementing changes based on these elements requires a likeminded owner / manager, it is also said such changes are reliant on a degree of; optimism, willingness to change, risk-taking and valuing competence (Kotey \& Meredith 1997). While these attributes are recognised as presenting a favourable platform for reform to be launched from, literature does point out that many owner / managers have "insufficient skills and competencies to analyse market conditions" (Lee \& McGuiggan 2008, p. 95). Therefore it is conceivable that while an owner / manager may possess numerous skills to deliver a physical product from their factory, a paradigm shift in market conditions can present a situation that requires an external and more sophisticated analysis to determine an optimal direction in a short time frame. From this perspective it is reasonable to assume that university research effort has assisted in filling potential gaps in the management skill sets of this organisation, despite research indicating "that many SME owners / managers perceive higher education as not relevant to their needs" (Lee \& McGuiggan 2008, p. 100). In this instance much of the success can be associated with combining the owner / manager's personal values, with competent research and delivering outcomes through targeted business strategies addressing the changing market.

### 2.2 Earned Value Management

Early investigations into EVM were looking for detailed confirmation that the method had support from practitioners and bodies of knowledge. Expectations arising from an introduction to EVM, through text book related material (Gray \& Larson 2003; Smith 2008), were that the method would have a significant presence across various aspects of 'project management' literature simply because of its representation as a powerful tool for project control and monitoring, and therefore important to the project management community. To some degree these expectations did not materialise as expected. Instead the method seemed to be only one of many project management research fields. This observation was confirmed in a tangible way by (Kwak \& Anbari 2009) placing it sixth out of eight identified discipline
categories with a seven precent share of research presence in top management journals over the last five decades.

Putting this aside, there was found to be abundant EVM literature available within the EVM researcher 'community of practice ${ }^{2}$ rather than the more general 'project management' field. Searching this narrower field delivered initial expectations of detailed support for the method at the application level in both academic (Anbari 2003; Kim, Wells \& Duffey 2003; Lipke et al. 2009) and practitioner publications (Fleming \& Koppelman 2006; Jacob 2005; Lipke 2006) to name a few contributors. Tapping into this research thread inspired a second session of literature review that was able to draw on experiences of implementing EVM at the host organisation. Through these practical lessons it was found literature took on a different dimension to the previous literature review as new; concepts, theories, methods and validation (Egnot 2011; Jacob \& Kane 2004; Kwak \& Anbari 2012; Lipke 2011a; Vanhoucke \& Vandevoorde 2007), were woven together with experiences from this research. The following paragraphs and subsequent sections of this literature review present findings from the perspective of this second literature review and lay down the foundation for the work presented in this thesis.

### 2.2.1 History and Development

Reviewing the history of EVM through its incremental advances and milestones with respect to a time line assists in gaining an appreciation of the methods development process as both a project management tool and a research field. Many papers make note that a "basic form of earned value analysis can be traced back... to the late 1800's" (Anbari 2003, p. 12) relating to "industrial engineers measuring performance in American factories" (Cabri \& Griffiths 2006, p. 6). It is interesting that these early concepts are associated with factory performance measures, being the basis from which this research and its objective were conceived. More specifically however the origin of EVM as a project management tool is associated with US Defense projects. Initially ' 35 criteria were defined by US Air Force acquisition manager in 1965’ (Fleming \& Koppelman 2006, p. 16), then in 1967 the US Department of Defense (DoD) adopted the criteria as their Cost / Schedule Control System Criteria (C/SCSC) (Anbari 2003; Cioffi 2006; Fleming \& Koppelman 2006). It seems over the next two decades

[^1]the method did not receive much attention in terms of development, apart from the introduction of a C/SCSC implementation guide being released in the early 1970's (Kwak \& Anbari 2012).

As with many evolutionary developments in industry; the specific moment of adoption of each concept is somewhat arbitrarily fixed, and hence there are varying degrees of interpretation as to how the system arrived in its current form. Although the early developments of EVM are not overly important to this research, obtaining an understanding of the literature and the various views presented by their authors is important. This background information and hence the views that stem from it, assist in making judgments about the concepts and how they best fit this application. As a result it was considered necessary to consult a recognised publication which most papers seem to reference at some point when discussing EVM. This led the research toward the two distinguished authors in EVM being; Fleming \& Koppelman and their most recent version (at the time) of the book "Earned Value Project Management" (2010 Fourth Edition). In Chapter Four titled "The Genesis and Evolution of Earned Value" they set out the evolution represented by the Phases which are listed below:
"Phase 0 - The factory floor: In the late 1800s
Phase 1 - PERT/Cost: 1962 to 1965
Phase 2 - C/SCSC: 1967 to 1996
Phase 3 - Earned Value Management (ANSI/EIA 784): 1996 to present"
This text greatly assists in understanding the development path and what influenced the system over this time. In concluding Chapter Four Fleming \& Koppelman (2010) point to a shift in the thinking around the late 1990's with respect to private industry and the new ANSI/EIA 784 standard. This shift in thinking was precipitated to some extent by the cancellation in January 1991 of the A12 Avenger II stealth Aircraft project which prompted research into EVM cost predictions (Henderson \& Zwikael 2008; Lipke et al. 2009) and is perhaps the catalyst for a significant increase in EVM development from this time.

Given that the A12 project cancellation is associated with cost performance data, estimate-atcompletion modelling and reporting practices (Christensen 1999) it is conceivable that this event influenced EVM's future not only as a project tool, and field of practice but also research field. In the same year the DoD Acquisition issued an instruction relating to the use of EVM (Kwak \& Anbari 2012), perhaps as an initial response to the difficulties of the A12
project? From this point in time; standards, legislation, policies and support documentation began to emerge relating to $\mathrm{C} / \mathrm{SCSC} / \mathrm{EVM}$ and contractor payment conditions. This remarkable US government related evolution has been recently mapped out in some detail by Kwak \& Anbari (2012). The content of their effort to capture this recent time-line is both helpful and appropriate to this discussion. Therefore the essence of their time-line (with some additional aspects taken from other research where considered important to the EMV story with respect this particular research project) is summarised below in chronological order:

- 1993 - US Government, Performance and Results Act requires performance measures for any program using US federal dollars;
- 1994 - Federal Acquisition, Sets average targets for cost \& schedule goals;
- 1995 - Federal Acquisition Regulation (FAR), introduced "a new category of payments to suppliers on fixed-price contracts ...called performance-based payments" (Fleming \& Koppelman 2008, p. 1), although not cited as EVM it is the opinion of these respected authors that the method has a basis in EVM concepts;
- 1996 - Industry, Re-write and reduces the initial 35 criteria, from the 1967 C/SCSC system, down to 32 criteria. Also replacing the 'Budgeted Cost...' terms (i.e. BCWS, BCWP, ACWP) with the more user friendly terms being the Planned Value (PV), Earned Value (EV) \& Actual Cost (AC). The new look package was bundled and presented as the Earned Value Management System (EVMS). (Fleming \& Koppelman 2006);
- 1996 - DoD Acquisition, Delivered mandatory procedures for major programs, and accepted the new 32 criteria for their C/SCSC system;
- 1996 - US Government, Discards the C/SCSC system for the simpler EVMS method, in an effort to encourage the private sector to take up the methodology (Anbari 2003);
- 1998 - Private industry research, Through the National Defence Industrial Association (NDIA) obtained acceptance of EVMS (Fleming \& Koppelman 2006) from the American National Standards Institute / Electronic Industries Alliance in the publishing of the standard ANSI/EIA-748;
- 1999 - DoD Acquisition, Adopts the standard ANSI/EIA-748;
- 2000 - Project Management Institute (PMI), Publishes a simplified EVM terminology;
- 2002 - Office of Management and Budget (OMB), Issued the 'A-11 circular' requiring EVMS to be applied across both government and contractor projects where development effort exists, regardless of contract type;
- 2003 - Private industry research, Proposes three different schedule analysis extensions to EVM (Anbari 2003; Jacob 2003; Lipke 2003), working towards a solution to the well-recognised gap in the EVMS suite relating to measuring time and forecasting duration;
- 2005 - PMI, Publishes the first Practice Standard for Earned Value Management;
- 2005 - DoD Acquisition, Revised their EVM policy to improve consistency in the method's use across their projects. The changes set requirements against project values and the intensity of conformity to the ANSI/EIA-748 standard. Interestingly this policy discourages EVM on fixed price contracts, contradicting the OMB 2002 A-11 circular;
- 2005 - US Government, Supplied a framework to developed an EVMS policy for IT projects, to support the OMB 2002 A-11 circular;
- 2006 - FAR, Issued a regulation based on OMB A-11 circular, being applicable to DoD, General Services Administration and NASA, requiring EVMS on major acquisitions. Jointly the civilian \& defence acquisition element also outlined the application should be based on particular contractor facts \& project circumstances rather than thresholds, and should not exclude certain contract types;
- 2006 - Department of Energy (DoE), Issued a policy order setting thresholds for the use of EVMS using ANSI/EIA-748 compliance certification with respect to project values;
- 2006 - OMB, Programing guide and supplement to the A-11 2002 circular, covering preparation submission and execution of budgets;
- 2006 - NDIA Project Management Systems Committee, released an EVM internet guide clarifying the 32 criteria presented in ANSI/EIA-748 to assist both government and industry meeting document compliance;
- 2006 / 2007 - Private industry research, Delivers results from a major study into the three different schedule analysis extensions proposed in 2003 (Vandevoorde \& Vanhoucke 2006; Vanhoucke \& Vandevoorde 2007);
- 2007 - NDIA, Release a revised version of the ANSI/EIA-748 standard;
- 2008 - DoD Acquisition provides supplementary rulings to that of the 2006 FAR EVMS requirements, retaining thresholds for cost or incentive contract and the level on conformity to ANSI/EIA-748. It also continues to discourage the use of EVM on fixed price contract; and
- 2011 - PMI, release the $2^{\text {nd }}$ edition of their Practice Standard for Earned Value Management, which includes an appendix discussing "Schedule Analysis using EVM Data" (Project Management Institute 2011 Appendx D), outlining the 'Earned Schedule' extension method.

It is worth noting at this point, before continuing, that apart from the 2006 / 2007 - Private industry research work of Vandevoorde \& Vanhoucke focusing on schedule forecasting the content of the above is represented solely by US based material. It is considered this may be a reflection of the research used for the above observations, which was not targeted at EVM history or development; but rather EVM use and application. However with the knowledge that EVM originated out of the United States, through the work of the DoD \& Government it seems despite this narrow demographic evolution for what is a globally "respected management science" (Fleming \& Koppelman 2010, p. VII) it realistically represents the core development thread of this tool. There are likely to be parallel developments of standards and supporting documentation developing in other nations such as AS4816 (Standards Australia 2006), however for the purpose of this research and understanding literature development, alignment with the US EVM time-line is appropriate.

### 2.2.2 Private Industry Uptake

Early introduction attempts of the earned value data techniques to private industry under the PERT/Cost banner between 1962 to 1965 resulted in almost complete rejection; the system was perceived to be telling "Industry executives...what management techniques they must employ and how they must manage their projects" (Fleming \& Koppelman 2010, p. 31). This reaction prompted the C/SCSC criteria approach where industry could achieve alignment with criteria using their existing systems. The added flexibility prompted the fundamentals of the earned value measuring techniques to start penetrating the private sector such as the construction industry where there was evidence earned value was being applied well but not called earned value (Fleming \& Koppelman 2002). Although this mid-1960s development led to better acceptance in principle the earned value element of C/SCSC was "widely adopted by the private sector during the ensuing decades" (Kim, Wells \& Duffey 2003, p. 375). Through
the period of C/SCSC reign the original intention of achieving compliance through flexibility dissolved as surveillance manuals and checklists intended as management system guidelines for implementation become elevated in status by regulators. By the 1980s system rigidity was again being resisted by private industry, a simpler form of the earned value elements of C/SCSC was needed for the much larger portion of non-DoD projects being undertaken for the US Government. Through these developments the simplification and ANSI/EIA-748 Earned Value Management phase took over from the C/SCSC era which can be considered to have ended in 1996 (Fleming \& Koppelman 2010, pp. 32-4).

Part of the modern EVM position has come from a 1997 occurrence captured as "earned value management system responsibility ... moved from ...government mandate to ownership of earned value by private industry... because it represents a viable best practice tool which project managers everywhere could use." (Fleming \& Koppelman 2010, p. 34). This point complements comments by (Kim, Wells \& Duffey) noting EVM uptake "is in the midst of rapid change. Increasing global competition and rapid technology development are pushing firms to give more attention to improving control of...projects ... " (2003, p. 375).

Apart from developments relating to EVM standards and overall system phases discussed above, the slow uptake between 1960 and the 2000s has been linked to other factors varying from high implementation and running costs, lack of understanding training and support, overly complicated and high administration effort, to more recent softer issues associated with "organisational-cultural related problems" (Kim, Wells \& Duffey 2003, p. 378). Despite these boundaries and its paced acceptance till the 2000s, research supports the view that EVM has strong merit in improving project performance (Anbari 2003; Anbari 2011). While the 'Performance / EVM' category is small in overall project management research under the broader management banner (Kwak \& Anbari 2009) the method has continued to gain popularity in the private sector, reflected perhaps by significantly more representation in management based literature from 2000, suggesting there is growing research interest in measuring project progress objectively using schedule and cost performance techniques (Kwak \& Anbari 2009, p. 442).

### 2.2.3 Schedule Analysis

The basis of earned value can be stated as "the accurate measurement of physical work performed against a baseline plan" (Fleming \& Koppelman 2010, p. 16) a focus that has
remained unchanged since the methods inception. Over time the formulas for illustrating this 'work performed' have remained sound in their form. Through such system stability the DoD has been able to track project outcomes with consistent measures for more than 40 years, giving rise (through the work of Christensen/Payne) to the now well documented fact that for such projects "the cumulative CPI did not change by more than 10\% from the value recorded at $20 \%$ contract completion point" (Fleming \& Koppelman 2010, p. 41). These long standing measurement observations in performance capabilities have made cost analysis a respected part of the EVM tool box for assessing current and future outcomes. Unfortunately the schedule analysis counterpart has not enjoyed the same certainty throughout its existence. This point is not made particularly obvious to the novice through statements which seem to place the two analyses on an equal footing; noting EVM "...can provide a reliable prediction of the final costs and schedule requirements for a given project" (Fleming \& Koppelman 2010, p. 16) or "...is a management methodology for integrating scope, schedule... measuring project performance and progress; and for forecasting project outcome." (Project Management Institute 2011, p. 5). These quotes, taken from high profile EVM references could be considered 'out of context', as both are really capturing EVM capability in its true generalised form, and furthermore both do elaborate on the schedule analysis limitations of the EVM method. However the point is that schedule analysis in EVM requires greater effort in understanding the real meaning of its indicators than does the cost analysis counterpart. And unlike the continuity which cost analysis tools have enjoyed, schedule analysis is in the midst of a development period which warrants a separate discussion to illustrate the changes that are occurring with this important EVM component.

Before exploring relevant events in the literature from 2003 (a time which can be identified with beginnings of the current schedule analysis story) there is an equally important point to be noted regarding a shift in representing the traditional EVM schedule variance (SV) measure. This shift is most evident when comparing the descriptions applied to schedule variance in the 2005 and 2011 Practice Standard for Earned Value Management (Project Management Institute). For clarity of discussion, these two descriptions are cited below as they appear in their respective releases:

2005 - "The schedule variance (SV) determines whether a project is ahead of or behind schedule. It is calculated by ..." (Project Management Institute, p. 17); and

2011 - "Schedule variance is very often misinterpreted as a time-base indicator, for example, are we early or late and by how much? It is not a time-based indicator but rather an indicator of the physical status (how much of the work has been accomplished).
The schedule variance (SV) determines whether a project is ahead of or behind schedule in accomplished work. It is calculated by..." (Project Management Institute, p. 58).

The addition of a preceding paragraph and the extra words relating to "accomplished work" following "behind schedule..." in the latest edition suggests the interpretation of this measure has been at the centre of some discussion since the first practice standard was published in 2005 and obviously an effort has been made to clarity the term. To seek further clarity on the Project Management Institute's position on this particular measure the PMBOK ${ }^{\circledR}$ Guide Fourth Edition (2008) under Chapter 6 titled 'Project Time Management' notes "Schedule performance measures (SV, SPI) are used to assess the magnitude of variation to the original schedule baseline" ( p . 162) followed by some discussion drawing in float variance, the relativity of the variance to the baseline and deciding on necessary action. There is also additional comment in 'Chapter 7 - Project Cost Management' being; "Schedule variance $(S V)$ is a measure of schedule performance on a project. ... The EVM schedule variance is a useful metric in that it can indicate a project is falling behind its baseline schedule. The EVM schedule variance will ultimately equal zero when the project is completed... EVM SVs are best used in conjunction with critical path methodology..." (p. 182). From this it seems the need to tighten SV in these standards was gaining recognition in 2008 and has obviously been an ongoing area for improvement as presented in the 2011 offering. Their timing reflects trends in literature which shows effort on this particular subject started gaining momentum in 2003 (as will be discussed) and more rigorous academic contributions emerged from 2006.

Having reviewed PMI's official publications on schedule analysis, the literature behind recent development is now explored. The time-line presented in section 2.2.1, noted that private industry / researchers proposed three different schedule analysis extensions to EVM in 2003. The common objective of these three contributions was to address the desire to measure time with respect to the same baseline plan used by the cost analysis while drawing on the same EVM metrics.

In 2006 these three forecasting methods were brought together in a study that looked at their behaviour and capacity to forecast total project duration (Vandevoorde \& Vanhoucke 2006), this was followed up with a specific study of these three methods using a large volume of
simulated project data, thereby controlling project performance and measuring forecasting capability under known conditions. (Vanhoucke \& Vandevoorde 2007). More detailed discussions relating to these two studies and numerous other EVM literature covering application and modelling topics will be found in subsequent sections; while the following Sections 2.2.4, 2.2.5 and 2.2 .6 will be used to discuss matters relating specifically to the introduction and development of the three forecasting methods proposed in 2003. The additional attention this area is receiving within this literature review is a reflection of the importance the 'time base measure / schedule forecasting' concept is to this research.

In March 2003 two of the three duration forecasting methods were published in what was then the Project Management Institute's College of Performance Management magazine called 'The Measurable News'. The immediate discussions below explore in detail aspects of these two important articles and also looks at subsequent publications that followed in short succession as the proposals took shape and the EVM community responded specifically to these emerging concepts. Following these initial two reviews the third of the 2003 duration forecasting methods (PV method) is introduced and discussed in detail before moving on to EVM application and more general project modelling.

### 2.2.4 Earned Duration (ED)

ED Article 1 - "Forecasting Project Schedule Completion with Earned Valve Metrics" (Jacob 2003, pp. 1,7-9) was the origin of the Earned Duration concept and has been cited in many publications since its release, more so for its views on application than as a forecasting method. The article commences with reference to that fact that Schedule Variance (SV) does not hold the same degree of reliability in performance measurement as Cost Variance (CV). Importantly Jacob points out that the word 'schedule' is commonly associated with time, however the SV unit is shackled to cost and therefore has no 'time' based meaning, other than a relative one. A negative SV value connotes being behind schedule and a positive value suggests being ahead of schedule, but also noting that SV converges to zero at the end of the project, eroding any capacity for it to forecast duration. He then points out that SPI is dimensionless and therefore presents an opportunity to use the term in forecasting duration. From here the proposed "Estimate of Duration at Completion" (EDAC) is presented. The method uses the terms; Planned Duration (PD), Actual Duration (AD) with the existing EVM metric SPI, combining as:
$\mathrm{EDAC}=[(\mathrm{PD}-\mathrm{AD}) \div$ Performance Factor $]+(\mathrm{AD} \div \mathrm{SPI})$

This equation results in offering a simple model for measuring time. The performance factor (PF) element at this point was represented by either the number one (1) or the current value of SPI, offering an optimistic or conservative forecast. The other important concept from this work was to address the situation of AD exceeding the PD (i.e. when the project runs over time). For this Jacobs proposed a switch in his formula, requiring the net value of ' $\mathrm{PD}-\mathrm{AD}$ ' to toggle to zero when planned duration becomes less than actual duration, hence the value of this subtraction cannot be negative.

ED Article 2-The principal article was 'revisited' in more detail in the Summer 2004 edition of 'The Measurable News' (Jacob \& Kane, pp. 1,11-7). The content of this publication coined the term "Earned Duration" defined as:
$\mathrm{ED}=\mathrm{AD} \times \mathrm{SPI}$
Equation 2.2
As a result, the original generic EDAC equation was now presented in the form of:
EDAC $=[(P D-E D) \div$ Factor $]+A D$
Equation 2.3
From here the paper diverges into a series of mathematical relationships, converging on two simplified equations for EDAC when $\mathrm{PF}=1$ or SPI. The need to toggle the formula when a project exceeds its planned duration remained however this was now achieved by substituting AD for PD in the above formulas. The result was a set of four equations covering the two PF values for both 'under / on time' or 'over time' schedule cases.

In both papers the author(s) discuss the application of forecasting duration with respect to; activities, work packages, control account levels, the critical path and the fact that the forecast numbers themselves do not provide "sanctity" (Jacob 2003, p. 9) in making decisions about action to be taken when a project is deviating from the plan. These contributions are believed to be at the heart of much discussion in future work; centred on what the SPI and SV measures represent, the value of forecasting to decision-making and the application of this tool. While these comments were perhaps secondary elements in these papers they have played an important role in understanding and making decisions about EVM for this particular application case. Aspects from these concepts will be discussed further in project modelling and subsequent methodology text where relevant.

### 2.2.5 Earned Schedule (ES)

ES Article 1 - "Schedule is Different" (Lipke 2003, pp. 10-5) is probably one of the most cited papers relating time based measuring of project schedule and forecasting. The discussion opens with an introduction to the behaviours of SV \& SPI from the perspective of their 'intuitive' representation, namely that they are somehow related to a time measure because of the word 'schedule' (Jacob 2003, p. 7). Lipke points out this behaviour creates difficulties for practitioners when presenting these 'project performance measures' to nonspecialist EVM executives (Lipke 2003, p. 10). Such comments highlight, for those new to EVM, there was an underlying issue with the term's definition or perception.

Lipke then proceeds to present his time based tracking methodology termed 'Earned Schedule' (ES). The source of the idea draws on much earlier work including that by Fleming as cited in (Henderson 2003; Lipke 2003; Project Management Institute 2011) where-by the EV is projected back onto the PV horizontally then vertically down to the horizontal time axis of the performance measurement baseline curve. The key element to determining time progress is the use of the reporting periods preceding this EV onto PV intersection point with the horizontal axis and the portion between this intersection and the end of this intersected reporting period. This portion is translated into a time value using linear interpolation and then added to the whole time units already earned. The general equation for Earned Schedule is defined by:
$\mathrm{ES}=\mathrm{n}+\left[\left(\mathrm{EV}_{\mathrm{n}+1}-\mathrm{PV}_{\mathrm{n}}\right) \div\left(\mathrm{PV}_{\mathrm{n}+1} 1-\mathrm{PV}_{\mathrm{n}}\right)\right]$
Equation 2.4
where n represents the numerical count value of the last full reporting period e.g. 5 (weeks) before the EV onto PV point intersects with the horizontal time axis. The EV and PV values are the existing EVM metrics, the subscripts indicate from which period these values need to be taken to calculate the portion to be added to ' $n$ '.

In theory, when graphically presented the ES calculation is relatively simple; however in application the method does require a sound grasp of the concept and the importance of the reporting periods. The analogies the method has to existing EVM cost performance metrics is however beneficial in translating the 'intuitive' meaning of SV and SPI into a form that can deliver to the non-specialist EVM executive what has always been a question relating to time; how far ahead or behind schedule is the project.

Having established the new term ES, Likpe was then able to derive alternative equations for the traditional SV and SPI measures with the addition of a term called Actual Time (AT), representing the time at which the measure of EV was taken. As a result the alternative time based SV and SPI measures were presented as:
$\mathrm{SV}_{\mathrm{t}}=\mathrm{ES}-\mathrm{AT}$
Equation 2.5
$\mathrm{SPI}_{\mathrm{t}}=\mathrm{ES} / \mathrm{AT}$ Equation 2.6

The subscript ' $t$ ' is used to indicate a time base measure, a format that has remained since its introduction and has been included by the Practice Standard for Earned Value Management Second Edition (Project Management Institute 2011).

The scope of this now landmark article was confined to the development of ES, paving the way to be able to measure schedule progress in a similar fashion to cost using the same EVM data set coupled with the newly defined $\mathrm{SV}_{\mathrm{t}}$ and $\mathrm{SPI}_{\mathrm{t}}$ measures. The conversation at this point however had not moved to forecasting other than alluding to the fact that there was opportunity to develop this avenue. Forecasting really evolved through the contribution of Henderson (2003) initially identifying a schedule predictor and demonstrating its potential, this was then followed up in another article (Henderson 2004) developing "two ES predictive calculative methods" (Lipke \& Henderson 2006, p. 27). Details of which are discussed below with other related literature.

ES Article 2 - 'Schedule is Different' was followed up quickly with a paper by Henderson (2003) in the Summer Edition of the 'The Measurable News' titled 'Earned Schedule: A breakthrough Extension to Earned Value Theory? A Retrospective Analysis of Real Project Data'. Early in the text he acknowledges "Abba and others have correctly pointed out that $S V$ (\$) is really a measure of the volume of work accomplished versus the volume of work planned" (p. 13) the latter statement suggests in hindsight the name (Schedule Variance) is perhaps an unfortunate choice that contributed to its mixed meanings across the more general project community. He then proceeded to apply ES to a series of small projects for the purpose of determining if ES would benefit the EVM practice in this example. Over this trial ES provided good correlation between the project outcome and its capacity to reflect progress, suggesting promise and recommending the method be subject to more research and testing. At the end of this article Henderson introduces two possible forecasting approaches:

Independent Estimate of (project) Duration;
$\mathrm{IED}=\mathrm{PD} \div \mathrm{SPI}_{\mathrm{t}}$

Independent Estimate of Completion Date;
IECD $=$ Project start date + IED

Equation 2.7

## Equation 2.8

Henderson points out the form of these equations is borrowed from 'practitioners' citing a 2002 online notice board comment by Reynolds "...to develop a calculated end date divide the elapsed duration of the baseline schedule by SPI(\$)" (in Henderson 2003, p. 22). This IED approach is also similar to the "Duration Variance" discussed by Jacob (2003, p. 7) the basis of which can be all linked back to the form of the 'Estimate at Completion' equation "EAC $=B A C \div C P \Gamma$ " (Project Management Institute 2005, p. 19). The paper closes by addressing the potential for the $\mathrm{SPI}_{\mathrm{t}}$ to be used with the IEAC performance factor, suggesting its ability to represent project performance and that late finishing projects particularly may benefit from use of this tool.

ES Article 3 - The third paper associated with the ES forecasting conversation (Lipke \& Henderson 2006) was again published by Henderson, titled "Further Developments in Earned Schedule" (2004) appearing in 'The Measurable News' spring edition. The content of this paper was based on pushing ES into the project (duration) prediction arena, presenting several proposed formulas which are structured on EVM cost based measures; while the specific details of these formulae are not important to this particular area of text the basis of his argument is important in understanding their development and proposed application.

Early in this third paper Henderson notes "ES does not provide direct schedule information, especially in relation to the critical path, consistent with long standing EVM advice and practice, the schedule should remain the primary source of duration..." (Henderson 2004, p. 16), a reminder of this observation is noted at the introduction to Fleming \& Koppelman's "Earned Value Project Management" (2010) and similarly in the conclusion to (Jacob 2006). Despite these continued reminders the desire to extract from EVM the capacity to forecast duration in a fashion similar to that for cost is recognised as a compelling goal (Lipke et al. 2009). Even if it is only recommended to be taken as a "sanity check on the trend and final direction of the project" (Fleming \& Koppelman 2010, p. 24) and used to "further
supplement the network analysis of the project schedule and critical path" (Project Management Institute 2011, p. 103).

On this basis Henderson (2004) proposed that ES generated $\mathrm{SV}_{\mathrm{t}}$ and $\mathrm{SPI}_{\mathrm{t}}$ values could be used in forecasting duration in consistency with EVM cost predictors. Through this work the Independent Estimate of (project) Duration at Completion (IEDAC) is "fully align[ed] to the EVM IEAC predictive formulae for cost" (Henderson 2004, p. 16) was paving the way for enhancements to the schedule analysis component of EVM. Given these two measures have now been accepted as behaving "appropriately throughout the entire period of project performance" (Project Management Institute 2011, p. 99) the approach was showing vision for the potential this 'breakthrough extension' could deliver. Using these principles Henderson continues to build on this philosophy by swapping $\mathrm{SPI}_{\mathbb{S}}$ figures with the equivalent $\mathrm{SPI}_{\mathrm{t}}$ values in established forecasting equations where factors such as the Critical Ratio (Anbari 2003) or Performance Factors are utilised to alter the $\mathrm{SPI}_{\$}$ when playing a role in schedule prediction and combining these into IEDAC formulas. In concluding the article a small data set is worked through with various duration forecasting methods and resulting in ES related measures performing well over the life of the project.

### 2.2.6 Planned Value Rate (PV Rate)

PV Rate Article 1 - "Earned Value Project Management Method and Extensions" (Anbari 2003) appears as a reference in most papers discussing EVM or any associated extension. The paper provides an extensive summary of the EVM method and its application. It is within this paper that the third time-based performance and forecasting measure was introduced as the Planned Value Rate (PV Rate) but frequently referred to as the 'Planned Value Method' in general literature discussions.

Details of the method are outlined in the paper under the heading "Time Variance" (Anbari 2003, p. 14) initially introducing the basis of the method which relates to the actual cost per time period (with respect to the projects reporting time frames). This actual cost over time function is termed the 'burn rate'. Drawing from this the planned value per time period concept is presented as the "planned accomplishment rate" and termed Planned Value Rate (PV Rate), defined by the BAC over the 'Schedule at Completion' (SAC) being the total Planned Duration (PD) of the project, the resulting formula is presented as:

$$
\begin{equation*}
\text { PV Rate }=\mathrm{BAC} \div \text { SAC } \tag{Equation 2.9}
\end{equation*}
$$

This relationship is used to convert the Schedule Variance (SV) from a currency to a time unit by dividing SV by the PV Rate. This new time base unit is termed 'Time Variance' the resulting formula is presented as:

TV = SV / PV Rate
Equation 2.10
The calculation provides a time base measure of the project status, noting zero indicates performance is on target, positive is good (ahead) and negative is poor (behind the plan).

The discussion then shifts to cost forecasting presenting various options to calculate an Estimate at Completion (EAC) depending on various assumptions regarding future performance. Anbari then moves back to time forecasting, where it is noted that "EVM has not been widely used to estimate the total time at completion, total project duration..." (Anbari 2003, p. 18). The paper proposes the capacity to provide a 'Time Estimate at Completion' (TEAC) can be achieved by applying similar principles to those presented in the (EAC) discussion. From here there are three numerically calculated formulas presented to forecast duration that are of interest to this 'Planned Value method':
$\mathrm{TEAC}_{2}=\mathrm{SAC}-\mathrm{TV}$
Equation 2.11
$\mathrm{TEAC}_{3}=\mathrm{SAC} \div \mathrm{SPI}$
Equation 2.12
$\mathrm{TEAC}_{5}=\mathrm{SAC} \div$ Critical Ratio $^{3}(\mathrm{CR})$
Equation 2.13
(TEAC Equations $1 \& 4$ (not shown above) are cases which require re-scheduling or assume despite slippage the project will be completed in the original duration and therefore are not of relevance to this forecasting discussion). The three TEAC formulas listed above are each worked through using the paper's sample project numbers and indicates various durations that can be presented as the forecast.

There were two interesting statements made during the presentation of this method. It is noted that the "estimated schedule duration... would have been obtained using CPM or PERT, if the schedule slippage... were on the critical path" (Anbari 2003, p. 18). This reinforces earlier quotes reminding the user of the importance of remaining vigilant about the critical path when using schedule duration forecasting. Secondly when reviewing equation

[^2]$\mathrm{TEAC}_{5}$, which provides the longest duration, it is noted that "This formula may provide a better indication of estimated time at completion, when budget is critical to the organisation" (Anbari 2003, p. 19). From this it seems Anbari is alluding to the fact that it is important to not only understand how various forecasting methods behave under given circumstances, but to also be aware of the project context with respect to the triple constraints of time, cost and quality when communicating a forecast.

### 2.2.7 Application

The basic mechanics of the EVM method are simple in that there are only three key elements PV, EV \& AC and through manipulation these elements deliver a range of measures that are beneficial to managing three critical elements of a project being: scope, cost and time (Anbari 2011). Unfortunately the method can be perceived, through its heritage as being "overly prescriptive" (Fleming \& Koppelman 2006, p. 16) for most projects being undertaken. The historic association of EVM with large projects contributes to polarised opinions about it. Supporters of the method see that the potential for application and the value it brings project management is worth the monitoring effort. Opponents foresee administrative burdens which do not warrant the effort (Fleming \& Koppelman 2010, p. 8) required to measure progress in such a way. As EVM has evolved, difficulties in application shifted from high costs and paper work (administration) to matters associated with organisational aspects such as: overly optimistic planning, inaccurate assessment, system knowledge or organisational culture (Kim, Wells \& Duffey 2003).

These more recent arguments illustrate a blending of organisational processes with project management practice. Applications that stem from this united foundation will likely require different EVM needs from those developed for a singular project only focus. It is becoming more evident that "management of multiple projects within an organisation should be considered globally in an integrated concept" (Aubry et al. 2012, p. 181). As the meshing of project management with business management gains significance it would seem there are opportunities to revisit how EVM could move beyond the conventional wisdom that it has only limited use in "the management of continuous business operations" (Fleming \& Koppelman 2010, p. 15) to one that provides a service to the project management function of an organisation by meshing its reporting mechanisms into the organisational decision making processes. (Aubry et al. 2012, p. 181). From this, the application of EVM and the outputs of
$\mathrm{PV}, \mathrm{EV} \& \mathrm{AC}$ have potential to serve a different role, as their application and reporting capabilities spread into an organisations functions.

It seems these 'organisation / project environment' aspects could develop into an alternative research thread of EVM in parallel to PM research as it investigates the concepts of " project ecology' relating to multi firm and multi projects... and the interrelationships between projects and their environment" (Walker et al. 2008, p. 169). Through this process, EVM may empower project management to play a more significant role in operational areas of a business and this is likely to influence the extent of its application, where it is being used in conjunction with organisational management to improve a firm's project performance. As this discussion is moving toward organisations, their structure and systems; further elaboration on EVM application in this instance will be addressed progressively in relevant sections.

The second element of EVM application that requires discussion at this point is the interaction between a specific project's content and the setting up of EVM, which influences how PV, EV \& AC respond, and as a result how EVM performs overall. Jacob (2003) points out EV is typically applied at the 'Control Account Plan' (CAP) level for cost performance and accepts this is useful when a project is going well. He adds however that there is a need to drill down to lower levels when problems present themselves, and emphasises the importance of using the project schedule rather than the elements of the WBS for forecasting. This approach is further discussed in (Jacob \& Kane) pointing out that "SPI calculated at the control account level is merely the ratio of the sum of EVs and PVs of those subordinate elements, either work packages or other control accounts" (2004, p. 1) and also expressed again in (Jacob 2005). The basis of this is summed up by Jacob noting that 'EV numerical data alone is not enough to monitor schedule performance and if EV data is used it must be applied to each activity and based on a pre-selected measurement method' (2006, p. 20).

Through examples Jacob presents a good case for this opinion, however he also acknowledges the need for balancing the administrative effort with meaningful reporting data so EVM does not become a burden (Jacob 2003; Jacob \& Kane 2004). This point along with the requirement to apply EVM at the work package or lower levels is frequently addressed by (Vandevoorde \& Vanhoucke 2006; Vanhoucke \& Vandevoorde 2007), where they acknowledge the reasoning but argue that "schedule forecasting at the cost account level or
higher... is the only approach that can be taken by practitioners" (Vandevoorde \& Vanhoucke 2006, p. 298) because of application practicalities. They go on to point out that EV metrics are set up to provide an easy and effective way to detect project problems early. Therefore they are not replacements for the critical path method, but an alternative tool and hence should not be subject to the same level of effort required when drilling down into the lower WBS levels for analysis. In addition Anbari suggests that while CPM/PERT are frequently used for schedule forecasting and EVM metrics are employed for cost forecasting, the two "methods have different underlying assumptions. CPM/PERT is primarily a planning tool, whereas EVM is primarily a monitoring and control tool" (Anbari 2011, p. 7). It is also noted that CPM/PERT does not take into consideration past performance when forecasting, therefore assumes future progress will follow the planned durations. Acknowledging this observation it would seem this well regarded approach to forecasting also requires caution in application, to ensure a projects performance is factored into its duration forecast. EVM on the other hand generally assumes past performance is a good indicator of future performance (Anbari 2011) and when forecasting with earned value duration tools it has been shown that adopting current SPI / SPI ${ }_{t}$ measures improves the forecast (Vanhoucke \& Vandevoorde 2007-2008). CPM and other modelling aspects will be discussed further in Section 2.3, where they more properly belong.

Returning to the point regarding applying EVM at high WBS levels, and in particular the forecasting capacity of earned value scheduling data, where views appear significantly divided. Fleming and Koppelman, as key authors and supporters of EVM, point out early in their fourth edition of 'Earned Value Project Management'; 'the notion that project time management can be achieved exclusively through EV data is questionable' (2010, pp. VIIVIII). Lipke's Earned Schedule (ES) method would seem to be at the heart of these time management / duration forecasting discussions, inspiring new research and many publications for and against, not only ES, but duration forecasting in general (numerous references are cited throughout this thesis in support of this claim). Interestingly despite the level of academic and practitioner activity since the 2003 duration forecasting methods of Anbari (Section 2.2.6), Jacob (Section 2.2.4) \& Lipke (Section 2.2.5) were introduced, and the fact the concepts originated in the US, its acceptance in its home nation has not gained the traction it seems to be experiencing in regions beyond the USA (Project Management Institute 2011, pp. 91-2).

The issue of the appropriate WBS level at which EVM is applied, the measurement criteria and the use of duration forecasting are all topics that generate debate in traditional project applications, where EVM is applied to the single, large and complicated project. However as project size decreases and the context of their undertaking deviates from the assumed 'typical EVM project application' (i.e. singular, large and complicated), application considerations play an important role in determining how influential these views are when adapting to the small project sector. An important question which appears to escape literature at present relates to what is a small project and hence at what point does the simplified models such as 'EVM Lite' (Fleming \& Koppelman 2007) become adequate. Going further (as this research is exploring) how much more can 'EVM Lite' be 'slimmed down' so it better fits smaller organisations' human resource capacity to deal with EVM administration, but still achieve the project management benefits that the integrated cost / schedule approach offers as it extends into the organisations project management systems.

As part of the research presented in (Kim, Wells \& Duffey 2003) they looked at how project managers use EVM depending on the project size; their findings confirmed as projects get smaller the methodology of EVM gets simpler and the level of detail also reduces. Another important characteristic of the small project (particularly relevant to this research) is discussed in (Lipke 2011a), where he points out the interrupted work patterns that are entailed in small short duration projects. Lipke illustrates, using EVM through periods of what he calls "Stop Work and Down Time" (2011a, p. 25) events, how inconsistent effort influences the established $\mathrm{SV}_{\mathrm{t}} / \mathrm{SPI}_{\mathrm{t}}$ indicators. He then introduces an alternative approach for setting up PV and measuring EV through these events so as to lessen the volatility that abrupt changes in effort introduce to the $I E A C_{t}$ values. He concludes by recommending that a special case indicator is employed for such applications ${ }^{4}$. This detailed work on specific EVM mechanisms contributes to being able to use the system in the small project environment. A third element in applying EVM to the small project is, overall how important are EVM capabilities for managing project progress and forecasting durations relative to the project scale being considered by this research. In practice managing time in the single project context of this research fits well with the concepts of "Management By Walking Around (MBWA)" (Gray \& Larson 2003, p. 327), where the project manager can 'stay in touch with what is really going on in the project' simply by communicating with the work

[^3]force and observing progress, and reviewing the schedule. This is possible in this application because the various project activities are being addressed in one location and the main deliverables are physically recognisable in the manufacturing stage, which constitutes the majority of the project effort. Therefore by being actually involved across the projects manufacture, the status can be visualised relatively easily.

From these literature observations, it is reasonable to ask how the application of EVM to this small project sector could improve the management of these projects when much of the material and debate talks of work packages, control accounts, measuring performance level within the WBS (Project Management Institute 2011) all of which have little apparent application value to the projects in question because of their small size. Smith suggests the effort to gather and process data on small project is not worth the effort (2008, p. 173), while Fleming and Koppelman "believe there is considerable potential in the universal employment of a simplified and user-friendly earned value approach in the management of all projects" (2010, p. 16). It is obvious that application of EVM does reach a point of fruitlessness as a project size converges to a simple 'job', however for smaller projects that contain elements of design, procurement, execution, testing and delivery there is benefit to be gained (albeit for cost management only) in some instances. EVM need not be solely about traditional performance measurement bound to integrating project scope, cost and schedule measurement to monitor progress (ANSI/PMI 2008, p. 181). Application can simply be to under-take historic project modelling in order to develop standard curves (Smith 2008, p. 173) for improving estimating and scheduling realistic durations, extending application for Project Risk Management (Pajares \& López-Paredes 2011) or forming part of a project management system that delivers a global approach to an organisations operations support by their project management functions (Aubry et al. 2012).

### 2.3 Project Modelling

Project modelling discussions can be broadly aligned with one of two literature threads represented here by a sprinkling of publications that can be aligned with one group or the other. The first thread represents theories and the breaking down of these into specifics regarding networks, modelling relationships and application (Kim, Wells \& Duffey 2003; Kwak \& Anbari 2012; Williams 2003), and also looking into project prediction (Czarnigowska, Jaskowski \& Biruk 2011; Lipke et al. 2009; Pajares \& López-Paredes 2011; Vandevoorde \& Vanhoucke 2006), analysing performance in a simulated environment
(Vanhoucke 2012; Vanhoucke \& Vandevoorde 2007) or analysing the numerous prescribed inputs and outputs (Cioffi 2006; Egnot 2011) that come with the EVM methodology (all of which have spawned an array of acronyms). For the most part these discussions are published through the academic sector and may be quite advanced in their mathematics and modelling proposals. As a result, for the average project practitioner, they can appear to deviate from practical application as they gain mathematical momentum in their quest to tackle more complex problems (Williams 2003, p. 17). The second thread in the literature traverses horizontally, scanning established tools (Henderson 2003, 2005; Lipke 2009), seeking alternative methods and application (Anbari 2011; Lipke 2004, 2006, 2011b; Van De Velde 2010), reviewing project behavioural characteristics (Christensen 1999; Henderson \& Zwikael 2008) and more recently exploring project topology (Lipke 2012) by drawing on parallel developments from academia (Vanhoucke 2012; Vanhoucke \& Vandevoorde 2007). In most cases this horizontal literature thread is more closely aligned with practice, typically presenting a simpler approach to illustrate their work through real project data sets and tools that have a place in the general project practitioner's knowledge base.

To illustrate the effect project modelling can impose on EVM; a simple example, taken from Jacob's contribution to the forecasting debate is presented. Through a small linear data example, which can be said to represent a 'project model' Jacob \& Kane are able to show that the three forecasting methodologies; Earned Duration, PV Rate \& Earned Schedule "have equal validity" (Jacob \& Kane 2004, p. 17) achieving $100 \%$ correlation under their test. While this conclusion is correct, for the example in question, the linear 'planned valve' data (the model) applied does not truly represent a real project's PV curve, i.e. these typically follow an "S" curve of some form, and therefore are not linear (Vandevoorde \& Vanhoucke 2006, p. 295). It is found that when the project is modelled more realistically these three methods deliver different forecasting results from their linear case and also perform differently to each other, i.e. they no longer achieve 100\% correlation (Vandevoorde \& Vanhoucke 2006, p. 298).

The above example, although simple illustrates the influence modelling can have on at least these EVM extension tools. From this perspective it is considered worthwhile to investigate relevant concepts presented in the above citations so as to bring to this research a sound understanding of project modelling and the relationship this has with EVM application. The above literature observations and use of a simple practitioner example to present a tangible
modelling outcome is certainly not intended to suggest the more advanced academic work does not have a place in this research project. However through readings it is apparent that the complex analysis of some academic material is above the needs of this practice based research where the objective is to derive a simple project management system and modelling approach that is applicable to the low technology industry in question. From this principal objective, literature tended to be taken from the practitioner domain, and whilst this provided important guidance on application theory, the academic material scanned frequently introduced important overarching theories that were adapted to strategies regarding the project / business interface. Drawing on the importance of these two different resources in developing this research outcome, the remaining content of this section will discuss relevant aspects from both literature realms.

### 2.3.1 Mathematical Modelling

A paper titled "The contribution of mathematical modelling to the practice of project management" (Williams 2003), discusses in detail the activities of modelling in the project field from the early 1950s. The work outlines the foundations of 'mathematical modelling' and how this has moved beyond the "standard project management decomposition model" ( p . $6)^{5}$. As such, the paper provides a good base from which to commence a discussion on project modelling. The following indented paragraphs explore some of the ideas and views presented in this publication that can be used to bridge across to other modelling material where it has relevance to this research.

An important concept pointed out by Williams is the classification of "the techniques of project management" (p.5) which represents the classical (or standard) project model denoted by the approach that a "project can be decomposed into its constituent parts and those parts are then each controlled' (p. 5). This strategy is used in conjunction with the three project elements of: cost, time \& scope. Where costs can be represented by a 'cost cube' consisting of the: Work Breakdown Structure (WBS), a Cost Breakdown Structure (CBS) and an Organisational Breakdown Structure (OBS) combining to form a three by three matrix and was part of the original US DoD methodology. Time scale (or schedule) analysis is based on activity-on-node or activity-on-arrow methodology. These techniques represented the majority of early modelling work formalised as the 'Project

[^4]Evaluation and Review Technique' (PERT). The final piece to this basic modelling framework is represented by scope and uses the Work Breakdown Structure or a form of milestone measures. Williams makes the observation that from a deterministic ${ }^{6}$ viewpoint the modelling of such basic elements in isolation and summing the parts together is a relatively simple process. Modelling becomes a necessity in predicting a project's trajectory as constraints, network relationships and the effects of decisionmaking are introduced to both the deterministic and stochastic ${ }^{7}$ project environments. Under these circumstances Williams claims the decomposition model is not able to reflect what actually happens in projects and suggests modelling ideas that are not shackled to traditional thinking require development to advance the project modelling field in a practical way.

In discussing the 'project managers' triple bottom line (cost, time \& scope) an important distinction is made between being "on time, on budget and on spec' [and] meeting cost, schedule and performance targets". This view is seen as acknowledging the dynamics that are present in projects, reflected by the trade-offs that occur between these three criteria over a projects life cycle. An example of the complexities introduced by this observation can be identified when considering traditional methods for the breakdown of the budget values with respect to planned scope. When the influences of these dynamic trade-offs are coupled with the inclusion of time phasing using the planned timeline (being the schedule). In this discussion Williams refers to earned valve analysis as "crude global measures, but very useful and finding increasing acceptance" (p. 5). It seems from these observations that the rigidity required by the EVM model (i.e. the emphasis on front end planning to produce the essential fixed 'Planned Value' curve) is a problem for modelling in this more dynamic context. Addressing network (time based) models using traditional PERT and CPM methods also makes assumptions the network is fixed with respect to uncertainties, while in practice these change as the project progresses, priorities alter and constraints (such as resources) adjust the critical path (p. 13). Recognition of limitations from fixed models is encouraging alternative approaches to these problems such as measuring 'cruciality" using "correlation between an

[^5]activity's duration and the whole project's duration" (p.13) or the replacement of PERT with the more powerful Monte Carlo simulation modelling (p. 15).

The above paragraph points to the desirability of building flexibility into models, and represents what seems to be a major shift in expectations regarding the future of project modelling. The traditional project management model has served the field well in developing software tools enabling advanced network analysis to be performed easily while including resource constraints and other real world limitations. However as projects become more complex [as distinct from complicated (Maylor, Vidgen \& Carver 2008, p. S16)] Williams refers to work in this project field as 'systemic models' suggesting under this scenario that "... while we might know the effects that impact upon the project and the outcomes from the project, it can be difficult to understand intuitively how the latter came from the former..." (p. 19). He notes that the relevance of this in relation to the "traditional project-management techniques and models" (p. 19) is presented in earlier work by [Simon 1982] ${ }^{9}$ suggesting "A complex system, is one in which the behaviour of the whole is difficult to deduce from understanding the individual parts" (p. 19). This implies that the decomposition model will be challenged to provide answers about future or past behaviour as project complexity or system dynamics increase their stake in the project environment.

The scenarios and methods proposed by Williams frames the efforts of modelling research into various phases, summarised as; "1960's - Scheduling (control), 1970's teamwork (integration) , 1980's - reducing uncertainly (flexibility), 1990's simultaneity (dynamism) for complex, uncertain and quick projects" (p. 18). It is noted that these later models (i.e. 1990's) are relatively simple, when considering 'complexity' and the idea that project management literature which continues to cling to the standard decomposition models is perhaps a narrow view of the project system (p. 21) with its emphasis on planning as opposed to a model that includes 'system dynamics' (p. 19). Drawing on the work of Malgrati and Damiani ${ }^{10}$ who identify limitations in the rigid frame stating "that the idealistic 'island of order' may suddenly turn into a more

[^6]realistic, very classic, 'iron cage"' (p.21). Williams alludes to the need for a model that can deal with stochastic change. Much of the 'systemic model' argument appears to stem from the need to build 'soft factors' and 'management actions' into models, suggesting that intangible influences that lead to managerial decisions have a great bearing on a project's behaviour. Therefore ideas from this led to optimising through simulation where there is opportunity to "re-plan as the project progresses rather than having to make an unchangeable plan at the start of the project" (p.19). It can be considered that the objective behind these ideas are attempting to achieve a synergy between the isolated concepts of modelling, project management practice and managerial effort, particularly relevant in a project enterprise where system dynamics from an organisation's operations extend across the project business interface.

In concluding on the specific ideas proposed by Williams, the passage discussing 'Hybrid Methods' makes an important point that while these more advanced flexible models, labelled as 'systemic models' support elements beyond the reach of the traditional 'decomposing' approach; they do introduce a degree of separation between the modelling process and the actual "activities and work items that are meaningful to the practising project manager" (p. 20). Acknowledging the importance of association between tangible project features and modelling scenarios suggests that modelling options are influenced by their domain. This approach leads back to what is possibly an important point when considering modelling strategies, where it has been found that project dynamics are generally related to "re-work cycle (including discovery of unexpected re-work), feedback effects on productivity and work quality, and knock-on effects from upstream phases to downstream phases" (p. 20). Identification of influences across such tangible elements may well only be possible if there are linkages between physical activities, the project environment and the modelling methods utilised to capture such indicators.

### 2.3.2 Modelling and Management

Returning to a discussion on general readings undertaken in this review, modelling has many levels of application, and the implementation of the EVM method is considered a form of modelling. Although the mechanics of EVM are fixed, successful application has relevance to Williams's view that modelling needs to include 'soft factors' in understanding project behaviour. There are numerous strategies that improve EVMs acceptance, use and
performance, relating specifically to how the method is embedded within the organisation. This particular view of modelling was investigated by Kim, Wells \& Duffey (2003) where it was found achieving flexibility in the EVM system's design allowed users to adjust the tool to suit varying project characteristics while remaining within organisational boundaries benefited the methods acceptance and use. While organisational communication was identified as a common element in improving EVM system use and performance, both of these characteristics have bearing on how EVM functions when decision making elements are built into the implementation model. Interestingly in a review of NASA's EVM culture Kwak \& Anbari (2012) also found that offering flexibility in project application, within NASA's project management framework (and hence its EVM requirements) produced a culture that tended to create a focused decision making point because of an adherence to these overarching organisational disciplines. Although these points are bordering on the organisational project management (OPM) field, they do illustrate the importance of 'modelling relationships and application' by drawing in soft factors, and when coupled with project modelling (EVM in this instance), does create a synergy for the organisation in regard to better project management decision making.

### 2.3.3 The ' $S$ ' Curve

Making informed decisions for a project is a significant function of managing projects therefore having a clear picture of a projects health is a critical component to this function. Project vision can only be achieved if there is good representation of the current status through measuring against a realistic plan. There is also a need to have insight into the likely future performance or 'project prediction'. Both subjects rely heavily on project modelling capabilities to deliver these functions and can be delivered very successfully using EVM when there is sound knowledge of the methods structure, its relationship with the plan and its vulnerabilities. The S-curve forms the basis of the EVM method, and while considered "...a far going generalization of the modelled project" (Czarnigowska, Jaskowski \& Biruk 2011, p. 12), remains a popular modelling approach (Williams 2003) despite literature reminding the reader it is a basic model. A vulnerability of this approach is captured by Fleming \& Koppelman, stating that "Earned value simply measures performance against the baseline plan, whether the plan is realistic, ambitious, or even impossible to meet" (2010, p. 139). Due to the relationship between EVM's critical baseline and the S-curve, it is apparent the modelling methods used to formulate this curve are important to the measurement outcomes of the system and hence its ability to deliver 'a clear picture of projects health'.

As the decision making process shifts from considerations about the present to what may occur for a particular project in the future, the secondary 'prediction function' of EVM becomes important to this discussion. Capability in this field remains bound to the S-curve model as all EVM data spawns from the numerical deviation between this 'plan value' Scurve and the actual progress represented by the 'earned value' S-curve. The capacity to forecast a project into the future is actually a non-linear extrapolation problem, however EVM's estimate at completion (EAC), "is a simple linear extrapolation" (Czarnigowska, Jaskowski \& Biruk 2011, p. 16). At this point there appears to be a paradox between the claims regarding the S-curves of the planned value and earned value. Recalling a previous argument where Vandevoorde \& Vanhoucke (2006) challenged Jacob \& Kane's (2004) on forecasting methods, here it was noted the planned and earned value S-curves are 'nonlinear'. It is believed the difference of opinion comes from the context of the two discussions; Vandevoorde \& Vanhoucke are (in this instance) considering the curve form using the nonlinear information based on current performance and remaining scope in the realm of the projects defined planned envelope. While Czarnigowska, Jaskowski \& Biruk are viewing the problem as one in which "future risk or effects of corrective measures" (2011, p. 16) are not included, being considerations that are aligned with the soft factors and more complex models noted by Williams. Putting these varying views aside the fact remains, that using data to model how a project will behave in the future is a complicated undertaking if any sort of reliability is to be claimed. Therefore it is evident the data from which these predictions are made are critical to how stable the model will be and hence how it will represent future performance.

The presence of reliable data alone is not sufficient to achieve good modelling, the first practice standard for EVM discusses "granularity and frequency" (Project Management Institute 2005, p. 4), its relevance for improving EVM modelling by adjusting the application level 'the granularity' (Jacob \& Kane 2004) or reducing the time between measurements 'the frequency' to address the non-linear problem (Jacob \& Kane in Vandevoorde \& Vanhoucke 2006, p. 295). A second limitation that exists for the schedule forecasting debate is the project schedule network, again Fleming and Koppelman discuss this, making the observation that a measured difference between the planned value \& earned valve (with reference to the horizontal deviation), at some point in the projects time line before completion, does not necessarily translate into the same deviation at the end of a project (2010, p. 149). Research
into EVM's forecasting methods (Vandevoorde \& Vanhoucke 2006), network structures and their relationship with modelling capabilities (Vanhoucke \& Vandevoorde 2007) has identified 'schedule topology' (Vanhoucke \& Vandevoorde 2009) as an influential element that adds light to the descriptive concerns of this relationship noted in Fleming and Koppelman.

### 2.3.4 Indexes and Forecasting

An interesting observation from EVM modelling literature is noted in discussions relating to performance indexes of cost and schedule. As noted at 2.2.3 the cost performance index (CPI) finds acceptance through statements such as "cumulative CPI is stable from 20 percent completion point regardless of the contract type" and "cumulative CPI [does] not change by more than 10 precent from the value at the 20 percent contract completion point" (Fleming \& Koppelman 2010, p. 41). Such claims are well substantiated through many years of project data acquisition and modelling using hundreds of DoD projects (Fleming \& Koppelman 2010, pp. 35-40). However as private industry increasingly takes on this method is it reasonable to question if these stability characteristics can be relied upon for the smaller and simpler projects of this sector. Henderson and Zwikael looked into this with a paper appropriately titled "Does Project Performance Stability Exist?..." (2008). Although a small study it does raise the question about transferring such generalisations to "projects of any size and type" (Czarnigowska, Jaskowski \& Biruk 2011, p. 17). Noting stability for the Henderson \& Zwikael (2008) researched samples was achieved at close to 80 percent complete, rather than the documented 20 percent. Henderson \& Zwikael also looked at DoD project data from an alternative source to that used in CPI landmark research ${ }^{11}$ and found "CPI stability was also achieved [in this DoD data set] very late in the project life cycle" (2008, p. 10). While the data underlying this opposing view may be an isolated case, it illustrates the significance of data and its representation in modelling. Relevant to this (as noted in 2.2.7) is the closing statement by Fleming and Kopplelman when addressing the growing interest in 'project time management' that "Earned value scheduling data by itself has a questionable time predictive capability" (2010, p. VIII) a view strongly shared by Jacob when introducing the frame work for his own schedule forecasting model by reminding readers that the 'numbers themselves are not the whole story' (Jacob 2003, p. 9). These well-

[^7]argued views raise the question as to why there is such support for cost data forecasting and not the schedule methods, despite modelling advances delivering methods that process schedule data in a like manner as that for cost methods (Lipke 2009), and supported through academic research (Vandevoorde \& Vanhoucke 2006; Vanhoucke \& Vandevoorde 2007).

A possible explanation as to the differences in cost and schedule forecasting can be taken from a mathematical representation prepared by Jacob when responding to claims by (Book 2006) regarding earned schedule reliability, its mathematical correctness and the poor representation $\mathrm{SV}_{\mathrm{t}}$ \& $\mathrm{SPI}_{\mathrm{t}}$ yields for schedule assessment. Jacob offers a simple but compelling observation regarding the two terms, as follows; "what applies for cost performance does not readily translate into what applies for schedule performance for the following reasons. The parameter of actual cost is a scalar quantity having only one characteristic, whereas the schedule data for a given activity has several characteristics, including its duration, its interdependency with other activities and whether it has float and how much" (Jacob 2006, p. 15). Reducing the earned value performance indexes to their core mathematical representation, would appear to be heading down the path of detaching the method's modelling function from important schedule ties, as noted earlier in Williams. While recent literature clearly acknowledges a tightening of the definition for schedule variance, as discussed in Section 2.2.3, it does not explicitly enlighten the practitioner as to why its representation has been adjusted. However the pure mathematical view-point can offer opportunity to frame the fundamental building blocks of these earned value performance indexes, in a way that grounds the theories which is considered important when seeking methods to extend modelling capabilities.

### 2.3.5 Index Domains

This mathematical viewpoint is explored by Egnot, where he discusses the possibility of commonality between earned value and earned schedule (2011). He identifies these two elements as the same idea but "operating in two distinct time \& value domains" (Egnot 2011, p. 8), observing the parameters and relationships between one domain and the other are complementary, while their mathematical behaviours correspond. Analogies between the two domains are represented by drawing attention to the concept of a 'Plan Parameter' being the 'Schedule' for time and 'Allocation' for the value domain. The benefit of this thinking comes when assessing the properties of the respective 'plan parameters'; schedule activities having a duration, start and end date, while allocation has a budget, lower bound zero and upper bound
equal to the budget. Using these concepts Egnot summaries this approach, termed 'Earned Progress', suggesting it is a "measurement of consumption of an asset in each domain...money in the value domain and days ${ }^{12}$ in the time domain" (Egnot 2011, p. 16). While this would seem to represent the two as equal, the element of 'interdependence' in schedules as noted by (Jacob 2006) and 'topology' or simply put network structures as summarised in (Vanhoucke \& Vandevoorde 2009) appear to also bear influence over schedule outcomes and hence forecasting, therefore adding to the complexities of this debate. A final observation by Egnot's, acknowledges the fact that time cannot be turned off whereas expenditure can, and therefore creates particular requirements for measuring time (Egnot 2011, p. 113). The difficulties time measurement poses for modelling is illustrated by Egnot through a series of scenarios considering the parameters of actual time, the planned start date etc. The mathematical representation taken by Egnot in this publication is considered (at this time) a fresh view on the subjects of earned value / earned schedule and particularly the framework around cost / schedule performance indexes. The abstract thinking applied to the domain concepts may well benefit future work as researchers push EVM models from both cost and schedule aspects to perform in an articulated manner from the common earned value data set.

### 2.3.6 Schedules Structure and Networks

The subjects of structural change, network relationships (briefly noted in earlier paragraphs above) and criticality warrant some discussion at this point. These characteristics are becoming more prominent in performance modelling as their potential to influence schedule outcome, and hence forecasting capacity is being better understood through research (Vanhoucke \& Vandevoorde 2007). Resulting developments appear to be stemming from increased complexity in projects, coupled with the desire to include aspects outside the traditional scope, time \& cost management triangle. The hybrid and systemic models' discussed by Williams (2003) may be considered the roots for some of these alternative modelling interests. It would seem effort to better understand schedule structure is a result of the increased interest in schedule forecasting, which in turn is pooling concepts from numerous researched subjects. In more practical terms the linking of existing knowledge about EVM application at varying schedule levels, i.e. the activity, work package or overall plan (Jacob 2005; Jacob \& Kane 2004), their responses in prediction (Lipke 2009) and

[^8]through the project life (Vanhoucke \& Vandevoorde 2007-2008). How these affect EVM's application (with respect to the schedule domain) is being advanced through more recent work relating to project types (Lipke 2011a), schedule adherence (Lipke 2011b) and the effect of network structure (Lipke 2012). In parallel there appear to be numerous developments seeking out project behavioural aspects relating to; structural change, dynamics of the critical path, and integrating project risk and expected variability into models (Pajares \& López-Paredes 2011). Earlier work exploring statistics as a tool for improving forecasting performance (Lipke et al. 2009) was based on applying these theories to traditional EVM data outputs to narrow the prediction. Interestingly these more recent 'alternative forecasting approaches' appear to be rooted to this schedule structure and relationship simulation (Pajares \& López-Paredes 2011). Other threads of research have been exploring patterns as described in (Czarnigowska, Jaskowski \& Biruk 2011) and while learning curves are not 'new' (Amor 2002) their alternative approach to scheduling has relevance to these newer schedule structure ideas.

### 2.3.7 The Scope of Modelling

Project modelling is a vast field of study and can plunge deep into theories that are well beyond the focus of this research. However as concepts were introduced through the above literature there is opportunity to note the reservations about many of the traditional tools in the classic project management arsenal. EVM for example has a dependence on a fixed project frame to measure against but newer theories are pushing flexibility to improve adaption and decision making. CPM is challenged by the ideas that "in practice the critical path changes over time" (Pajares \& López-Paredes 2011, p. 617), does not have capacity to take into consideration past performance (Anbari 2011) and the fact that the critical path can have alignment with the "relationship between the duration of an activity and the duration of the total project" (Pajares \& López-Paredes 2011, p. 617) rather than solely the network. These factors lead to an apparent increased interest in the 'Monto Carlo' simulation approach as an alternative to the traditional tool. SPI and CPI are recognised as tools to indicate delay or cost deferral and they have no relationship to structural change that can lead to a project getting out of control (Pajares \& López-Paredes 2011). Finally there is the high profile and hugely debated challenges that SPI presents for EVM's schedule arm.

Questioning long standing theories is an important strategy to developing a robust system for managing projects. But is it of equal importance to remain grounded to the objective of such
systems, which is to improve practical application. This point reminds us of the importance of basic indicators like EVM's capacity to measure and produce a numerical output, and in so doing provides "an independent view of what is occurring, an objectivity that brings into view otherwise invisible threats" (Van De Velde 2010, p. 2). To achieve good measurement requires planning in detail, setting a benchmark or start point, which in turn forms the basis of contract management and if done well by achieving schedule reliability, contributes to the forecasting and organisational credibility (Richey 2012).

Each tool or modelling technique will present advantages and disadvantages, so having an awareness of their function, specific techniques and usefulness with respect to accuracy and scale context, are primary knowledge prerequisites for application decisions. As previously noted in 2.2.7, when considering functionality subtle differences such as traditional CPM, being said to represent a planning tool and EVM having a monitoring function (Anbari 2011), help to establish basic waypoints. Hence, when newer theories are added to complement such traditional tools, the extension they provide has a clearer objective. Drawing on recent work by Vanhoucke (2012) one such example presents EVM in the context of control techniques from a 'top down' perspective responding to dynamic project information, and is now being coupled with schedule risk analysis, noted as being a 'bottom up' control technique stemming from the static project information stream. Migration of these different models and their data streams enhance overall project decisions because there is representation from the coal face (the dynamic feed reflecting status) which may alter the context of previously identified risks (static information, with likelihood and severity linked to status). Examples like this reflect the growth and integration of modelling with project management practice. As many of these more recent managerially adept modelling methods become more articulated with main stream project management, it is likely the role of the project manager will continue its perceived trend of becoming the strategic professional. These observations suggest there is a "need for PM professionals [to be] reflective practitioners" (Walker et al. 2008, p. 169) in a quest to broaden their management capacity from project initiation to dealing effectively with increasingly complex projects. As modelling methods advance, managerial skills mature and academic research binds theories together the idea of an alternative project management triangle consisting of: "organisational context, project management implementation and organisational strategy" (Aubry et al. 2012) will see project management as a management practice gain recognition in the 'business management' sector.

### 2.4 Organisational Project Management

Very early in the research program it was realised EVM could not be plugged into a project without a supporting organisational frame-work being present. This reality introduced the need to review material that would assist in establishing a suitable project management system to support the research objectives. The resulting 'literature review' was commenced as a reaction to a potential research problem, rather than a planned review as was done for project modelling. Initially this review provided guidance as circumstances or opportunities presented themselves to improve the position of the central EVM theme. The broader management subject however became of interest as there were synergies observed between this material, EVM needs and the researcher's management role within the host organisation. As a result the review explored the subjects of portfolio management, project management systems, managing projects in business and finally concluded in process and structure related subjects. As this review was linked to the progressive development and comprehension of project management and its methods (or systems), the following 'literature review' is presented as a chronological history (by subject) of the readings completed, the concepts presented and the ideas or links to application that developed from each source, rather than clustering author theories together as done for project modelling. In this form, the literature review is able to represent the extraction of theories and their influence on thinking and ultimately the resultant system developments undertaken in parallel to the research. The subsection headings categorise the themes that were significant to this practice-based organisational project management research journey.

### 2.4.1 Project and Portfolio Management

Initially there was a review of general project management theory relating to the planning phase taken from Stal-Le Cardinal \& Marle (2006). The method of 'activity decomposition’ was discussed and analogies were made between its project intent and its application in engineering design principles. This connection enabled past problems in planning and scheduling multiple equipment projects to be better understood. It was also noted in this review (and drawing on pre-research literature scans) that there were typically major differences in the scale of projects discussed in literature to that of the LAP project environment, this presented some difficulties (in later work) relating concepts discussed with the application in question. A final point taken from Stal-Le Cardinal \& Marle related to sharing priorities and resources, and the consequences of not being aware of the needs of other projects leading to "global constraints impossible to solve" (2006, p. 229). This
scenario had links back to papers reviewed for the research proposal where multiple project management required a strategy that has an overview of the project portfolio and must be separated from the details of the singular projects. This point was significant for the host organisation as management structure at the time of research commencement was lacking portfolio management and had the overarching management personnel involved in singular project detail.

The next publication that aligned with project management as a subject covered the matching of project management tools to different project types titled "Discriminating contexts and project management best practices on innovative and non-innovative projects" (Besner \& Hobbs 2008). Among other research outcomes, results showed that innovative projects used project management tools significantly more than non-innovative projects. This outcome supports the general observation that the industry being investigated for EVM application (being non-innovative) was lacking in formal project management capacity and tool utilisation. This relationship was extended to also suggest higher performers in project management who utilise the available tools \& techniques are also likely to have established a high level of project management maturity and this aspect is the most significant difference between high \& low performers in the project management context. Within discussions relating to innovation success the term "better-phased gates processes" (Besner \& Hobbs 2008, p. S124) was cited and prompted additional investigation into stage gate processes which resulted in significant resolution of functional boundaries and their communication with respect to the PMS development.

Besner \& Hobbs went on to acknowledge that a singular project management methodology cannot be applied across all projects and pointed out that "higher uncertainty is significantly linked to better planning and control procedures and tools" (2008, p. S124). This view confrimed the host's experiences with what is termed 'small project syndrome' where insignificant projects or tenders are approached with lax management and frequently escalate into major difficulities as their context and content were not subject to the systematic approach that larger more risky projects were subject to. Extending this understanding Besner \& Hobbs suggest "High performing organisations develop specific project management capabilities and adjust their practices to become efficient innovative leaders" implying that a PMS would have flexibility built-in to adapt to varying project circumstances by maintaining
a level of rigour to ensure low end projects do not have the opportunity to escalate out of control.

### 2.4.2 Project Management Systems and the User

The first literature reviewed that fell under the systems subject approached the issue from the perspective of what effect "project management information systems ... have on project managers and project success" (Raymond \& Bergeron 2008). A good criterion was presented for deciding what makes a useful project management system. The key points were the system needs to address the individual (project manager) and the organisational needs and if it is built around function then it will get used - being used adds strength to the system which in turn delivers improved confidence. It was also noted a key measure of success for a system is if it provides opportunity to leverage a project manager's ability by providing confidence in decision making, resulting in improvement to project management professionalism. Within EVM application discussions (Section 2.2.7, p.35) empowerment of the project management role (and its personnel) was noted in a similar context seeking enhancement of specific skill sets to take a lead role in management effort as the organisation grew in maturity. Enhancement of project management skills and confidence through support of information systems was seen as a likely benefit to assist LAP project engineers in dealing with clients who are sometimes limited in knowledge of the product and manufacturing processes, but frequently seek to hijack LAP's planning logic by reducing decisions down to simplistic levels. Aspects of this connection were key criteria discussed in the project proposal and therefore considered an important system element to take forward in the developments.

The review of Raymond \& Bergeron (2008) introduced the fact that system users, and their interaction or response was a significant consideration in the broader subject of organisational project management. The understanding of the relationship of people in projects and communication with both internal and external project members was considerably enhanced by Carù, Cova \& Pace (2004). The paper looked at what makes a successful project, through considering factors beyond the time and budget elements, seeking value in improving the overall experience from a client and project team view point. By drawing on historic industrial age projects (BBC Worldwide Ltd 2004) examples of success in this context were realised. From this view it was observed the host organisation's project environment was not particularly rewarding due to the ad hoc nature of the system. There was enormous effort applied in reacting to problems due to lack of planning and consequently little reward or
satisfaction was achieved. Therefore research needed to address more than just project time and budget issues, but also contribute to improvements in work place culture by using system information to manage processes and build confidence across the organisation as whole, to achieve a better project environment and better day to day social experiences for employees.

Carù, Cova \& Pace (2004) also talked about the 'languages' of the project and its change through the various phases. This shift in language occurs frequently during the host's projects, as there are high level meetings with clients and also technical meetings with engineers. A common issue observed was the engaging in technical aspects with project members who do not understand these specifics. As a result the contact can lead to a skewed focus resulting in plans being changed to suit the clients understanding. This problem was linked back to earlier comments by Raymond \& Bergeron (2008). Therefore communication and guidance on project language should also be a consideration when documenting the project management method and preparing training for the host's project engineers and managers.

Gaining an appreciation of project language with respect to project phases and contexts raised the point that planning a project with a client's view point in mind could be used to diminish the difficulties discussed above. This is most likely an important aspect when preparing a schedule, as there is a fine line between useful detail and excessive information that becomes over-constraining. Therefore if the initial planning is carried out with regard for the client's limited detailed knowledge and covers critical elements only, then there is opportunity to alter tactical details without diverging into excessive technical debate. This approach also has a connection to Williams's (2003) project modelling view of planning for changes, instead of working from an ‘unchangeable plan’ (Section 2.3.1, p.43).

The third paper reviewed under the PMS context was titled "Project management systems: Moving project management from an operational to a strategic discipline" (Cooke-Davies, Crawford \& Lechler 2009). The paper opens up a discussion in relation to the fit of project management systems with an organisation's strategies on project management and the projects themselves. This led to an explanation of traditional PMS being somewhat ossified, whereas it is now understood PMS design requires flexibility built into the implementation mechanisms to adapt to the project context assessment process (as described in Section 2.4.3). The paper was centred on testing the idea that "project success is related to choice of
the 'right' management approach relating to specific project characteristics" ( p .110 ) and the "extent of fit or misfit between an organisations drivers of strategic value and the specific characteristics of its $P M S^{\prime \prime}$ (p. 112). In responding to these questions a concept that emerged which seemed different to other literature (at that point in the research) was the acknowledgment that the project portfolio and the organisational complexities were capable of affecting individual project outcomes. It was also noted project management activities themselves can actually influence organisational strategies, introducing the idea that " $a$ project is not always subordinate to the strategy of a parent organisation" (p. 110). Considering this statement in the context of the host's business environment it suggested that the PMS once established is like any other organisational function, in that it is a live process that requires continual adaption and improvement. Lessons from projects and changing business conditions need to be assessed against the system and fed back into the strategy of the PMS so the system itself evolves and adapts with the organisation to new opportunities and risks.

From the analysis, the authors developed a preliminary matrix model which has the objective of being able to identify where an organisation is with its PMS strategies (direction) and where it should be in regard to its business interests. The model used drivers of project differentiation and financial value to identify the fit between the PMS and the business activities and to then determine the applicable management approach. While the model was a simplified example, the theory was adaptable to the application being considered for the host organisation. The model's vision provides a stepping stone in understanding how PMS structure could move away from the standardisation frame. While this traditional approach offers good organisational efficiency and control it limits creativity and over constrains the project management process, making it difficult to implement for users and therefore limits PMS application across the portfolio.

While the paper's structure was quite academic the outcomes were tangible and bound together concepts from other literature that had significant benefit to planning the PMS objectives depending on the project context. This contributed greatly to identifying what needed to occur at the host organisation to enable project management to work better. This is considered an important milestone for the industry objectives of this study.

### 2.4.3 Managing Projects in Business

Project management within the business context was initially identified as a separate literature thread in Maylor, Vidgen \& Carver (2008). This paper introduced the notion that management of projects can't simply be achieved by applying a specific management methodology without consideration to the project context. This idea was interpreted to imply the organisation, the client and the project's place in the client's larger project plan were connected to the project's context. This hierarchy of needs therefore required a customised adaption of project management methodology achieved by drawing from a pool of relevant theories.

A critical element to understanding this literature and the framing of subsequent views regarding project context, system adaption and comprehending project modelling discussions came from the clarification provided in differentiating project complexity vs. a complicated project, as discussed in "Complexity in Projects" (Maylor, Vidgen \& Carver 2008, p. S16). This simple yet significant clarification grounded the research to a point of reference that established a method of classification for both practical project problems and the application of research theories.

Through the review of this paper it was clear the subject of project management was migrating into the business and management fields, but its standing with respect to the existing body of knowledge was not high since "much of the literature would be best described as accepted practice rather than best practice [and] highly prescriptive" (Maylor, Vidgen \& Carver 2008, p. S16). These views were linked to Williams and his opinion of the classic 'decomposition model' being limited as project complexities increased. Questioning of established theories merged with concepts from Carù, Cova \& Pace (2004) as discussions turn to the status of theories, concluding there is a need to "theory build" (Carù, Cova \& Pace 2004, p. 532; Maylor, Vidgen \& Carver 2008, p. S16) and carry out testing of these in the context of the broader 'managing projects in business' context. These views introduced the notion that development of theories (or tools) can-not necessarily be seen as the one-stop solution to project management issues. Therefore it was considered development of how projects are assessed and existing theories applied would have greater benefit for this research outcome.

The final development lesson taken from Maylor, Vidgen \& Carver (2008) alluded to the need for management to deal with project aspects, such as technical issues while maintaining control of the business process. This point added value to past experiences with the host organisation whereby project momentum had dominated the business as a whole. By connecting the responsibilities of project management in business to encompass control of the business process the scope of the project management system was taking shape. The assessment and resulting management strategy that needed to be applied to the project was captured well by concepts and phrasing of the "organisational response" (Maylor, Vidgen \& Carver 2008, p.S15), suggesting the process gives opportunity for the business to find the best practice for the specific technical and social dynamics presented by the project. This was seen as a means of extending the project team out so the project becomes part of the wider business environment. It was thought the development of this concept would benefit the host organisation in its day to day project and business functions.

### 2.4.4 Structure and Processes

As literature moved the oversight of project management away from specific project activities and deeper into organisational aspects, the need for balance between these processes and those of the organisation became relevant. Kuprenas (2003) assembled a paper - of interest in this context - that had been based on the application of theories and documenting the outcomes rather than researching theories in application and documenting the results.

The basis of the paper covers the change to a matrix management structure and reviews the identification, creation, implementation and outcomes from the changes. While specific details in the paper were not significant to this research the overall management strategies applied were important in considering the challenges that would arise in applying EVM and a PMS to the host organisation. Central to the connection between this literature and the research context, was the need to adapt a matrix structure that can assist in resource allocation and cross discipline interaction needed on complicated projects. This approach fits with environments where functional management and project management co-exist under the one organisation. For the host, this scenario was represented by its production needs interacting with project management. Analogies were also recognised with the presence of multiple projects and therefore managing priorities so that the outcomes presented by this literature had relevance to this research scope.

The structure presented by Kuprenas was robust and well configured to the environment in question. More importantly however, observing the fact that the process of researching an organisation's structure and its operational problems can then be used to design a well configured PMS is beneficial knowledge to have when confronted with such a task. It was noted that the EVM specific implementation methodologies of Kim, Wells \& Duffey (2003) discussed in Section 2.2.2 were also representative of these broader system strategies. However the example provided by Kuprenas drove deeper into the organisational functions, recommending that job functions, their boundaries and responsibilities form part of the systems structure.

The final literature reviewed in the wider organisational project management context related to the structure and process sub-heading and hence its placement in this section. As ideas and methodologies evolved across the sub-sections of 2.4 using material from various research efforts, a cross section of authors and their agendas a consolidation of systems thinking with respect to engineering methodology was seen as a necessary closing review strategy. This was undertaken using chapter thirteen of "Systems engineering coping with complexity" (Arnold et al. 1998), and the relevant Chapter titled "Project and the Enterprise" (pp. 280304). This publication provided a more consolidated backdrop than individual research papers which generally needed to surrender some breath of view in order to attain sufficient depth of thought. Based on Arnold's et al. (1998) consideration of the whole project management system structure, and as understood from previous literature but writing with respect to the host organisation's context, the following paragraphs summarise important aspects.

Finding analogies between literature and the host's organisations project scale with respect to describing the different levels (or phases) of project management has been challenging throughout the research. In this chapter there is reference to what is termed 'the program' which captures the "[need] to deliver an operational capability" (Arnold et al. 1998 p. 280). This example and its adoption of 'program...' instead of 'project...' is a useful term to describe the PMS's management role which can be termed program management, as opposed to the portfolio management role (i.e. caring for all the 'projects' while the project engineering role deals with a 'project'). While these layers are simple enough, without clear
definitions and labels it is difficult to communicate system roles and responsibilities with staff, clients and auditors.

While establishing sub-elements of the project management system, it was observed that there was a need to cycle through numerous projects to achieve a robust strategy. Within the text of this chapter there is reference to the fact that "supporting systems for... technology management cannot effectively be constructed within a single project..." (Arnold et al. 1998 p. 280). Through this cycling process there is an opportunity to observe and analyse issues that bypass the system, hence inspiring a revision to the system design. These iterations result in product and manufacturing knowledge becoming embedded in the system. Over time this transfer of knowledge from personnel to the company via the system is actually harnessing the organisations IP and achieving what can be described as innovation. It is interesting to note that in 2008 Engineers Australia presented a discussion paper on manufacturing which outlined 'delivering innovation' as a critical component to the survival of manufacturing organisations in Australia in the coming years. In 2012 innovation remains a key concept in material being offered in response to ongoing Australian manufacturing issues (Engineers Australia Innovation Task Force 2012; Prime Minister's Taskforce on Manufacturing 2012). While the host is a low technology business it seems innovation can still be applied via management and services rather than through the medium of the product itself.

A large part of the text in this chapter discussed the use of stage gates. While these have played a significant part in developing the current system (although their role was not appreciated until late in the research) their definition and place in the system to date was not well understood. The concepts behind staged management in this reading were illustrated in the Chapter section titled "Managing through stages". Material here outlined the need to provide "...processes to manage products from cradle to grave" (Arnold et al. 1998 p. 281). This passage provided guidance on evolving the product mindset from the physical only to one that encompasses the systems to deliver. The host's (LAP) analogy to this concept can be stated as 'tender to archive' and the products value for LAP is the embedded information about the equipment's engineering and build history. A second key development was gaining an appreciation of gate sub-sets, captured in part by the statement "Each stage gate is a real project, whose purpose is to produce information, not a real end product for the users" (Arnold et al. 1998 p.281). From this there are perhaps two types of gates to be utilised in this environment, it can be said; one provides access to the field and the other to a yard within the
field. Yard gates represent a process within a business function, as a result they are for the most part self-managed to allow the necessary flexibility to suit individuals. Whereas field gates represent a commitment to the next phase and therefore cross system boundaries. In doing this there are responsibilities to the organisation to ensure requirements are met. Achieving better definition about gates will help to explain system boundaries and the responsibilities of associated personnel when moving within and across functions. Definitions and subsequent procedures will help to ensure all key information is transferred, albeit in stages, to accommodate rapid response to project requirements.

Understanding the concept that innovation can also be applied to business functions and not just physical products introduces a shift in the mindset about the host's potential market. Previously there was always a focus on the end product and its inherent 'quality' as defined by mid 1990s quality assurance literature. However it is evident major clients are now seeking more than the end products in new contracts so matters like; build history, management effort, project communication and risk management are playing a greater part in deciding contract award. Coupling these newer deliverables with earlier thoughts about applying innovation is giving new meaning to statements such as "Marketing's job is to capture intelligence from the marketplace and use it to drive development" (Arnold et al. 1998 p293). Whereas once material like this would have been brushed off as high end talk for main-stream consumer markets, it is now obvious the host can improve its position by researching and developing smart systems that deliver these less tangible products and therefore make the organisation as a whole more marketable. The recent award of a very large project (with respect to the host's project context) can be attributed to this thinking, as the client apparently considered the host's project management systems better than most reviewed in tender and therefore less risky to the contract.

The chapter presents a capability model (Arnold et al. 1998 p.295) relating to system engineering processes, "defining a number of levels against which the maturity of an organisation's processes may be measured ...". There are five levels presented being:

- "Level 1 - Initial, No definable processes in place, projects are conducted by competent people and heroics." (This was the start point for the host)
- "Level 2 - Repeatable; Basic project management processes are in place ... planning and managing new products is based on experience with similar projects." (At the conclusion of this research this level has been achieved)
- "Level 3 - Defined; Processes for management and engineering are documented and integrated into a standard process for the organisation. All projects use an approved, tailored version of the organisations standard process." (At the conclusion of this research integration and the use of a tailored version has been achieved, the company is now up to documenting these processes)
- "Level 4 - Quantitative; Detailed process and product quality metrics are fully employed. Meaningful variations in process performance can be distinguished from random noise and trends in process \& product qualities can be predicted." (Consistent measurement of the host's capacities commenced early 2012, but is expected to start to add value from January 2013. The decision to seek measurements came from having better control of the organisation and this seemed a natural progression to be able to better understand the host's performance and the businesses capabilities. It is interesting to observe that, this in itself is the next level in maturity and was the host's next obvious step in improving, and occurred without prior knowledge of this model)
- "Level 5 - Optimising; The organisation has quantitative feedback systems in place to identify process weaknesses and strengthen them proactively. Project teams analyse defects to determine their causes, process are evaluated and updated to prevent recurrence of known types of defects."

These objectives have been a long term goals of this research, while the basis for this final level forms part of ISO9001; a system to effectively capture, analyse and respond in a controlled strategy has been a noted missing link in the ISO models application. Recent adoption of Microsoft Office OneNote ${ }^{\circledR}$ has started to break down the consolidation issues of past strategies, however it is expected the system will take another twelve to eighteen months to bed down the process and fully integrate them from completion of this research program.

### 2.5 Chapter Summary

A two-phase literature review was undertaken, initially scanning obvious areas of interest that could tie the objectives of this research together. The second session of review came from developing a greater understanding of EVM and its desire to represent the project through
mathematical modelling and the effect organisational decisions can have on project outcomes, which the models must then be able to reflect.

At the outset information was sourced solely from EVM's fundamental operators. To develop a basic approach the Australian Standard (AS 4817-2006), was initially reviewed. This document provided sufficient detail to make the necessary start to experience EVM in application and output. Being an Australian Standard its adoption fitted well with the industry application that was attuned to such local standards.

Initial study on how EVM methodology could be meshed with the host organisation brought into sharper focus the impact that the research would have on the business. At that stage it was considered a literature review was necessary on the topics of: 'small and medium enterprises' (SME), organisational project management and EVM covering its background, uptake issues and performance measurement options as well as application strategies. Each topic required a different approach as their relevance to the core EVM application theme varied. The SME review was broad seeking confirmation of the host's place in the SME classification, it also looked for ownership characteristics and management styles of these business types. Organisational project management was approached to seek guidance on PMS development, using (mostly) academic research papers to foster idea development. The EVM subject although technical at times was undertaken in-depth, looking for cross pollination of theories in application to shape the methods application approach using current theories.

As part of this enquiry it was confirmed that the host organisation is a 'Medium Business', though closer to the 'small' end of the spectrum (Australian Bureau of Statistics 2002). Among several findings in relation to the usual characteristics of SME's, it is recognised nationally that where manufacturers are affected by global factors, then the promotion of innovation is significant in businesses surviving such external change (Engineers Australia Innovation Task Force 2012).

Organisational project management reviews were not specific and relied on the PMS development imponderables to prompt readings. This resulted in a meandering review process selecting subjects of interest in support of the problems at hand in implementing a system to supplement the EVM course. The supportive role of this review, meant literature was consulted throughout the duration of the research period rather than a focused session.

Following some initial EVM trials that provided essential hands-on experience attention returned to the literature surrounding EVM and its ancillary topics. After examination of the evolution of EVM from preceding systems such as PERT and C/SCSC and the general array of support for and uptake of EVM, interest was turned to the mechanisms of EVM. It was evident EVM in its original form has limitations in schedule prediction. Additional research exposed Earned Schedule (ES) as an alternative time measuring and forecasting method (Lipke et al. 2009) to the classic EV analysis using schedule variance based on the parameters of earned value and planned value. This was a relatively new thread of literature originating in Lipke (2003) and had significance for this research. Some concern was felt in relation to the finding by Lipke (2011a) that on small projects, inconsistent effort (as can occur at LAP) can adversely affect established indicators produced by EVM thus raising questions about the net benefits of EVM application at very small scales.

Further examination of the available literature drew attention to the great influence that project modelling can have on EVM and its extension tools. The connection between modelling and EVM application at the detailed level prompted the second stage of the literature review process. The approach to this subject was one of intense research into theories within project management processes and their capacity to encompass the more recent objective of having capacity in a managerial context.

Through the modelling review connections were made between the traditional decomposition approach where 'granularity and frequency' (Project Management Institute 2005) are recognised as having pronounced effects on the utility of EVM outputs while the simplicity of the EVM model and its reliance on the fixed plan were connected to the view that "Earned Value simply measures performance against the baseline plan, whether the plan is realistic, ambitious, or even impossible to meet" (Fleming \& Koppleman 2010, p. 139). Beyond these practical modelling cases, advanced theories for more complex modelling were then considered taking in issues of activity criticality, schedule structure and mathematical representation of performance domains and the underlying platform that forecasting operates from. The final more abstract concepts of modelling managerial decision making and the inclusion of business influences was also well presented and provided relevance to literature being consulted from the organisational project management subject.

Essentially, each tool or technique has its strengths and biases. A clear understanding of the function, relevant scales and limitations of each is essential to their purposeful application. It is of great value to the process of implementing EVM and more so a PMS to take concepts from research efforts and map these to the applications being sought.

## CHAPTER 3

## 3 Research Design

### 3.1 Outline

Research, in broad and simple terms, endeavours to increase or refine knowledge, for some applications it develops specific answer to specific questions; it can also entail studying situations with respect to their environment. In narrowing the scope of this research to design the objectives there are two aspects of EVM that offer a start point. The behaviour of EVM is related to dependent variables such as: schedule accuracy, its topology, measurement methods, distribution of project activities and their costs, most being aspects that can be set in a fixed frame (the specifics). The application of EVM on the other hand is associated with independent variables related to the dynamics of the project management system, its people, the business environment, its system(s) and the context of the project in question (the situation and constraints). Research design for this particular undertaking therefore needed to consider both of these dependent and independent frames of EVM. As a result, the design evolved into two distinct areas posing questions that would contribute to knowledge in a specific way as to the projects in question (behaviour) and also in a generalised sense (application). However it is noted from literature that EVM cannot simply be plugged into an organisation, "instead it must be associated with overall organizational approaches..." (Kim, Wells \& Duffey 2003, p. 382) and therefore research design needed to embrace wider project management and system development subjects that stem from the industry partner's business activities.

Targeted fields of research were built around the goals of strengthening the knowledge of the researcher in the areas of: project performance, project and portfolio management and systems engineering. For the industry partner, skills in these areas were considered necessary foundations for introducing innovation to their structure and process through better project management of product delivery. While these areas are significant fields of study in their own right, the benefits of this work needed practical application relative to the industry partners' particular problems. Under this scenario similar knowledge development regarding product and manufacturing cycles needed to be woven into the research project and system orientated goals.

The resulting research program required considerable effort in designing and implementing a range of management-orientated activities, aimed at establishing an adequate project management system (PMS). This system provides the foundation for the second element of the research scope, being specific investigations into the behaviour and application of the project management tools 'earned value' and 'earned schedule' with respect to the industry partner's manufacturing projects. Throughout the development of the literature review it was clear the work of; Anbari, Fleming and Koppelman, Henderson, Jacob, Lipke, Vanhouke and Vandevoorde as well as many others have contributed significantly to understanding the characteristic of EVM. Accordingly, seeking to validate the general theory of EVM and its extension Earned Schedule was not considered a research question that this work needed to address as such. Therefore the design of the research has remained aligned to the industry host's desire to improve project management and apply EVM theories.

### 3.2 Management-Orientated Activities

### 3.2.1 Context

Research design for the 'management-orientated activities' was an evolutionary process that incrementally introduced change and then observed outcomes. This trial and error process balanced the articulation between the research management frame in question, and the activities of the industry partner. The resulting developments were dependent on, and largely dominated by the host organisations business activities over the research time line ${ }^{13}$. To successfully identify and integrate the necessary changes in the business, it was important to explore numerous theories relative to the setting being investigated. Project management systems, engineering management, portfolio management and managing projects in business were found to be relevant fields of study that feed into this research context. Their inclusion allowed existing practices to be compared with best practice as presented in literature and therefore assist in building up suitable theories relating to management strategies to fit the application of this business and the overall project management improvement objectives.

### 3.2.2 Objectives

The decision to include 'management-orientated activities' in the research scope was take because of the dependency EVM has on its overarching management structure (Kim, Wells \&

[^9]Duffey 2003). With this in mind the purpose of the management scope is tailored towards developing management skills which are able to guide the organisation in a way that shifts its project content from an isolated management function to one that has a central role in the organisation processes. Promoting process change towards projects is considered an approach that should deliver project orientated data for the organisation. Finally by channelling effort into linking data outputs with day to day processes it is likely free flowing data streams will become available for EVM application and in doing so is expected to reduce specific administration effort needed at the project face for this tool to function. From this the management-orientated research objectives can be summarised as: 'Achieving a project management system(s) that best supports EVM utilisation in the fabrication environment'.

### 3.2.3 Questions

Researching projects in a live business environment where the organisation is maturing in parallel to the research time-line poses difficulties in establishing a frame for developing and responding to a static research question that spans the development period. The key elements in setting a question (time and organisational structure) are fluid and hence specifying a fixed reference point to measure from is problematical in a quantitative sense. An extension to these issues is the fact that management decisions affecting projects in this SME manufacturing environment can occur rapidly and in response to issues external to the research subject, such as adapting to legislative changes or servicing on-going client needs regardless of shop planning. Further difficulties in establishing a formal managerial research context were found to be caused by the necessity to maintain existing systems in the main stream business process to support ongoing manufacturing, so changes that would have been desirable to introduce as a test block scenario to measure the effect, were introduced incrementally to ensure continuity in operations could be maintained.

Although these dynamics make the 'management-orientated activities' for this particular undertaking unsuitable for setting a quantitative research question there is opportunity to respond to a more general qualitative approach. Acknowledging the fact that the start point for this research was a blank canvas in terms of project management systems it is useful to make observational assessments of the development decisions and organisational response as a mechanism to capture these experiences. Information gathered through this process can then be assessed regarding the influences that have occurred as a result of EVM and 'Project Management System' (PMS) implementation. Therefore the research question within the
context of the 'management-orientated activities' is proposed as $\mathbf{H}_{\mathbf{1}(\mathrm{PMS})}$ - "Establishment of an EVM based PMS decreases organisational related project management difficulties"

### 3.3 EVM Method

Deciding on what elements of EVM needed to be investigated by this research was guided largely by what was already in place through the work of others. The EVM literature review process (Section 2.2) provided a clear picture of the methods use, limitations, available outputs and hence identified areas of interest where effort could be applied to assess the tool in relation to its fit with the application in question. The need to also address specific project status questions proposed at the conception of this research was also a consideration. These initial ideas about specific EVM characteristics were useful in focusing objectives on how the method and the research could help to add value to the end product for the host organisation. As previously stated, these concepts related to understanding and communicating; "where is the project at" and "when will it be completed" (Section 1.1, p.2).

The above paragraph encapsulates the component of the EVM modelling process that fits with the context of Flemings note regarding EVM merely measuring against a base line (Section 2.3.3, p.44) and the views of Williams and Czarnigowska Jaskowski \& Biruk (Section 2.3.1, p. $41 \&$ Section 2.3 .3 p. 44 respectively) seeing EVM as a relatively simple model, because these investigations are dealing with the individual project, the fixed plan and the measuring or monitoring against this plan. Never-the-less having capacity to objectively view the project's status provides the necessary vision and capacity to communicate with the organisation and the client about the project in question. Therefore pursuing research design along this line has relevance to the initial questions and also builds information that will support the more complex problem of managing the project in the portfolio and the 'project management' of the manufacturing activities.

The other consideration in this EVM research design process is the modelling of the base line itself. Again the work of others has laid the foundation from which this can be developed, however considerations for this component are taken more from the abstract discussions found in project modelling (Section 2.3) than in the specifics of EVM (Section 2.2). The alignment between base line preparations and project modelling stems from the congruence between a projects scope and how this is represented in the schedule, which ultimately delivers the baseline plan. From literature, there are two aspects to the transformation
between scope and the baseline. Firstly, representation of the scope using the schedule delivers what is described as the schedule structure or topology (Section 2.3, p.48). For this particular application, being small projects, the work by Vanhoucke \& Vandevoorde appears to have provided a stepping stone for Lipke to begin exploring the small project characteristics of EVM (Lipke 2011a) and the closely related longest path concepts (Lipke 2012) which despite having what seems to be a complicated setup and tracking process is moving this particular element of EVM work towards the project behavioural aspects observed in this research. The second part to the process of transposing scope to baseline is the representation of the schedule by the time phase budget, here it is necessary to compress the schedule network to minimise the measuring process, providing opportunity to converge toward the idea of "EVM Lite" (Fleming \& Koppelman 2006) by simplifying the administration burden when monitoring.

Keeping in mind three key elements (specific outputs to assess the project status, alignment of scope and schedule structure and thirdly the representation of the schedule network by EVM's time phase budget), the design process can look at the type of projects to be investigated, the objectives of this work and finally specific questions that can be answered by applying EVM to this project environment.

### 3.3.1 Project Type

Selecting the type of projects to target for testing the adaptability and value EVM may achieve, requires alignment between the projects selected and the projects that have significance for the organisation. To clarify significance in this context, it is implying a focus on what type of projects represent the majority of the organisation business and therefore what product holds a high stake in the project portfolio. Assuming beneficial results are achieved the overall value to the organisation would be maximised through enhancements associated with core product.

The other consideration that played a part in selecting the project type was how complicated was the target product. The number of parts and the connection between them (Maylor, Vidgen \& Carver 2008, p. S16) bears on how difficult the product structure would be to model. This became an important consideration because of discussions in literature regarding EVM's tendency for high levels of administration in both setup and maintenance (Section
2.2.2, p.24), and therefore a relatively simple modelling scenario was favoured to learn on and take to the organisation.

The resulting decision was to maintain trials with pressure vessels only. The regular presence of pressure vessel projects throughout the research window provided opportunity (once data collection requirements were resolved) to select specific project outcome examples to trial against known literature aspects. The choice also lent itself to utilising a series of repeat vessel projects where comparisons could be made about potential product learning curves (Amor 2002), observe external factors that altered outcomes despite being a repeat project and to provide a common project plan and scope as reference point for drawing out conclusions about EVM behaviour.

### 3.3.2 Objectives

Ideally EVM will be able to establish itself as a beneficial tool to supplement other project management methods for LAP; however its core objective is to offer a measure of the projects progress with respect to effort and to communicate this progress, particularly to clients. Earlier discussions questioned how important the EVM capabilities might be with respect to managing progress and forecasting given the relatively small project size and simple construction (Section 2.2.7, p.37). As literature was reviewed subtleties between these capabilities were recognised, therefore core objectives noted in the opening sentence represent a focus on 'burn rate' (Section 2.2.6, p.32) being a cost over time or effort to progress factor rather than predicting an end date per se. From this, research questions that need to be asked are related to gaining project management benefit by being able to see a projects status and future outcome. There is a common objective between forecasting and future outcome, for the time domain this is about assessing the completion date while for the cost domain its purpose is to provide guidance on where the project will finish financially along the trajectory of cost over time. Although this research commenced with a time measurement agenda the capacity to foresee future costs is of interest in addressing tighter financial management requirements (Section 5.11.2, p.183) that have developed in the later stages of the research window due to external business pressures.

### 3.3.3 Questions

Setting the research questions has been done using the above framework and also taking into consideration how they will be tested given the observational context of the research. It is also important that these hypotheses and any conclusions deliver informative outcomes to the
host business and the industry sector they are aimed at. For this reason the following hypotheses are offered in order of relevance to the original research proposal and desired outcomes for the research setting.

The principal proposition $\mathbf{H}_{1(\mathrm{EVM})}$ is: 'EVM can be applied to an SME, manufacturing heavy pressure equipment and in doing so deliver net benefits to its project management activities'.

A useful benefit for the target industry which could be implemented if EVM methodology became common practice on suitable projects would be the ability to forecast delivery for client communication and end cost for the fabricator, therefore proposition $\mathbf{H}_{\text {2(EVM) }}$ is set to: 'EVM forecasts are accurate and reliable enough to be used in reporting manufacturing progress to clients and progress value to the fabricator'.

The worthiness of EVM methodology is supported by existing literature, however the strategies for application are dependent on the context of the particular projects or project environment in question. Therefore an opportunity to explore modelling aspects of the method that could improve its useability for this application are available, this presents $\mathbf{H}_{\mathbf{3}_{(\mathbf{E V M})}}$ considering: 'Excluding the cost of raw materials from the time-phase budget (TPB) does not significantly impact on indicator performance and simplifies user interaction'

If the above hypotheses can be satisfied, then opportunity exists to extract additional benefits from the research by feeding EVM data into front end project activities such as estimating and preparing preliminary schedules. If such a loop can be closed and in doing so improves the project tendering process it would add value to EVM uptake as a management function for the organisation, by contributing to a business process rather than just a particular project, this consideration sets up the last proposition $\mathbf{H}_{\text {(Evm) }}$ will consider: 'Having historical project data available in EVM format improves tender assessment, project risk \& contract management related functions for the organisation'

### 3.4 Development

The topics worked through to address the stated objectives and questions, can be summarised as; project management processes, ability to communicate project status, adaptability of EVM to a particular product and potential for extended organisational benefits used a
blending of firm theories from literature, change management coupled to observational development, as well as specific project planning, management and modelling activities. Working through these various subjects enabled established theories to be tried and tested in a practical context, a process that placed the necessary learning activities into a live business case study. In contrast to the dynamics of the overall development process, the setting of fixed academic frames throughout the research helped counterbalance the commercial tendency to seek a rapid continual improvement cycle that can preclude the opportunity to complete a rigorous analysis of a process. By forcing critical review of outcomes there was opportunity to consider the correlation between theories (and literature) and the behaviour of a system before moving on to react to the next shift in the business environment.

The developments described in the following subsections discuss the evolutionary phases that the management-oriented activities and EVM objectives passed through over the course of the research window. The development process ultimately shaped the research design, by moulding the initial goals into a form that nested industry partner objectives with the necessary setup and validating rigour to ensure the investigations were seeking out what was being asked by the research questions and hence delivering a robust assessment for the business case. This process is recognised as an important component in ensuring the academic industry partnering process can deliver to SME needs as discussed in Section 2.1.

### 3.4.1 Project Management Systems

At conception of the research (2008) the organisation had recently completed several significant projects that highlighted the need to establish project management as a function within the organisation, similar to the way in which the engineering design function had evolved in the preceding years. At this time there was no specific structure for handling projects. Accordingly, they were largely left up to the assigned project engineer, who for the most part was allocated the project based on their present work load. Apart from the randomness of allocation and the personal approach of each individual to managing projects, staff had no project management training and the planning and management of a new project was undertaken in isolation from other projects being handled by the organisation.

This disjointed and informal approach had obvious difficulties in meeting project requirements in any sort of controlled fashion. Despite the sporadic chaos and continual need for a reactive management style, projects were completed at least functionally to the client's
expectations. Elements of the project that suffered from this ad hoc 'system' were: time, cost, organisational efficiency, staff from both the project and operational areas of the business and the client. Through experiences and observation of other projects running in parallel there were obvious 'fixes' required, but at this early stage they were related to individual aspects of a project's execution. It was not until literature was consulted (mid 2009) regarding; classic project management theory, sharing priorities and resources (Stal-Le Cardinal \& Marle 2006), project management systems (PMS) and their connection with individual and operational needs (Raymond \& Bergeron 2008), consideration of the project experience (Carù, Cova \& Pace 2004), the broader project context (Besner \& Hobbs 2008; Maylor, Vidgen \& Carver 2008) and the co-existence of project and functional management activities (Kuprenas 2003), that the subject of the PMS and its overarching approach began to be recognised as a prospective solution. In parallel to this development process the requirement for EVM to have a support structure in place to channel data, set boundaries and system flexibility had been identified as a necessity for the tool to function and more importantly have opportunity for uptake (Kim, Wells \& Duffey 2003). Material from this select group of literature was used to provide the foundation for introducing the necessary changes in the 'management-orientation' activities and EVM application.

Recognising the wider context of doing projects in a business environment, the PMS development process took on a whole-of-business approach rather than the EVM specific system concepts conceived at the start of the research. Looking more broadly at the organisation it was possible to start identifying functions and their processes in the organisation with respect to their contribution to the 'project' objectives. The review process was extended to evaluating strengths and weaknesses of these functions and processes and also how the research was or could influence their outputs. From here work commenced in parallel on both the PMS and EVM adaption (discussed in detail in Section 3.4.2).

Initially PMS development focused on establishing information streams EVM required to function, following an initial trial on a project that established the theories, the method was introduced to a project engineer to gauge user response. While the theory was understood it was obvious a simpler version was required to address administration effort, consideration was also needed regarding the degree of affinity staff felt with EVM use. Another notable issue was the rigidity of the PMS, displaying signs of over constraining the project engineering role. However the method's financial outputs were gaining interest in relation to
contract management and estimating, which in turn drew in elements from the accounting system. Observations in flexibility needs and the depth to which the PMS activities had started to penetrate the organisation moved these management-orientated activities away from their EVM focus towards the business management realm. At this point the activities of PMS development shifted to a more strategic view, and EVM was recognised as a tool rather than a system and therefore would sit within the more powerful project management system. Development of the PMS was now identified as a critical component to the research and the organisation needed to build on the concept to improve project management maturity. Of particular importance at this point of development was the recognition that a PMS requires customisation to an organisation so as to achieve a good fit with the project environment and also take into consideration the need for flexibility so as to deal with the varying project content that may exist in the portfolio (Cooke-Davies, Crawford \& Lechler 2009).

Stemming from project management needs, integration between functions was reviewed and shaped to suit desired outputs needed for EVM, improved project control and functional networking. This presented a development phase that utilised the concepts of flexibility while ensuring essential system boundaries maintained alignment with organisational strategies. As a result of this global approach aspects such as correlation between estimate worksheet and project budget modelling were targeted to improve overall system unity along with costing models and reporting outputs being aligned with accepted financial management classifications.

The next major development was initiated by the desire to roll out projects to the now established project engineering function based on a fixed 'project launch platform'. The idea behind this phase was to get better data stream compliance (being an identified EVM essential system boundary) while avoiding over constraining the project engineer role by requiring conformity to labyrinthine setup requirements. In identifying the processes needed to output to a platform concept it became apparent the platform strategy itself could also offer a solution to the problem of transcribing project scope and requirements from the estimating / tendering stage to the design, planning and production phases. Pursuing the objective of achieving the project launch concept coupled with the integration of accounts and contracts (estimating / tendering), to allow EVM to work, resulted in the establishment of a project management office (PMO) that sits between the now identified contract function and project engineering. Through this development phase there was a shift in organisational thinking
from one that was centred on the end product to now focusing on processes undertaken to deliver that end product.

The final 'management-orientated' developments made under the research banner evolved out of defining the PMO function and its inputs and outputs. Coupling this work with identifying critical components and knowledge transfer that must cross functional boundaries during a products initiation, planning and execution phases were initially recognised when reviewing material on stage-gate project management processes (Denney 2006). Integration of stage-gate concepts into the broader organisational management strategies gained significant traction when there was an understanding of the networking between functions, the management levels and their duty of care with regard to organisation and operational capacity, portfolio management and individual project management (Arnold et al. 1998, pp. 280-304 Chapter 13, Projects and the Enterprise). The approach of developing a PMS using inputs from project management needs, organisational strategies and operational functions (Aubry et al. 2012) is evolving into a system that utilises EVM inputs and outputs in conjunction with weekly operational management activities to improve overall project management objectives and organisation planning.

### 3.4.2 EVM Adaption

The focus on EVM as a central theme in addressing questions relating to project status came about because of its capacity to track and visually display project status. These attributes were considered a good alternative communication avenue to explore from the Gantt chart tool then employed for this purpose. Early expectations had assumed both time and cost modelling were established practices and the development and implementation would be relatively simple, a 'plug in solution'. It was quickly realised through PMS work (Section 3.4.1) that the method in isolation was not going to be able to achieve its goals without a supporting structure in place. It also became apparent early on that within EVM itself there were numerous aspects to consider which influenced the method's measuring process and therefore response. The most concerning point to be noted following a brief re-introduction to the method's detail was the issue surrounding schedule variance becoming unreliable at the later stages of project execution. At this early stage of literature review schedule variance was taken at face value to represent an indicator of 'schedule time' and therefore posed a possible shortcoming to the time reporting objectives set out in the initial research concept.

Several months elapsed between commencing the research formally and getting the first EVM curves established. During this time basic data requirements were identified and changes made to the host's systems to extract enough information to setup a single EVM trial. This period was also used to review the basic EVM mechanics (Standards Australia AS4817-2006) and to investigate the concept of Earned Schedule (ES) (Lipke et al. 2009) as an alternative to the forecasting difficulties of traditional schedule variance. Concepts from the above references and identified organisational processes that would deliver data were brought together in the form of a custom EVM / ES spread sheet that became the basis for implementation. This spread sheet has evolved over the course of the research to the point where it has become a consolidated reference for the host's PMS and supporting functions with respect to individual project information.

It also needs to be acknowledged at this point that the proposed application and testing requirements were dependent on actual projects being available. This dependency was linked to the external business activities via project contracts being awarded to LAP. Therefore development opportunities were to some degree a risk for the research as the planned activities were contingent upon suitable projects coming on line at appropriate times. Experience in the lead up period to research commitment (mid 2007 - mid 2008) suggested this vulnerability would not manifest itself. However, the GFC did cause a slow down for the industry host between mid-2009 to mid-2011. Nevertheless the impact was not sufficient to preclude the presentation of enough suitable projects to complete investigations as intended.

### 3.4.3 EVM Trials

The first suitable pressure vessel project (T001 ${ }^{14}$ ) had a timely commencement just prior to resolving the basic setup issues. As a result it was targeted as a trial opportunity to apply the theories and begin the implementation exercise. Through this trial process it was identified that both 'frequencies and granularity' (Project Management Institute 2005, p. 4) ${ }^{15}$ required investigation, the ES method was also introduced in this trial and its $S V_{t}$ output was presented on the classic EVM 'S' curve plot illustrating planned value, earned value and actual cost. This early work provided useful feedback on how the ES extension could be used

[^10]to elucidate a projects time measurement. The trial also highlighted the significance that the administration burden could entail in running the method in a human resource poor / high workload project environment. The issues surrounding these concerns were related to the level of detail included in setup and monitoring (granularity issues). Another noted potential for further investigation was the varying results between samples at different frequencies towards the end of the projects reporting period. The trial also drew attention to the challenges that would come from having to address changes in scope, which are a common feature in 'engineered-to-order' vessel projects being the prime target for this EVM application.

A second simpler project (T002) (mid 2009) was then setup for trialling. Despite being a less complicated project, administration effort remained an issue that needed reviewing once the basics of the adaption processes were resolved. In addition to the 'S' and 'ES' curves this project also introduced basic forecasting methods and their curves using the long standing PMI cost indicator (BAC/CPI) and the $\mathrm{IEAC}_{\mathrm{t}}$ formula $\left(\mathrm{PD} / \mathrm{SPI}_{\mathrm{t}}\right)$ as presented in Lipke et al. (2009). Inclusion of these simple curves illustrated instability in the cost forecast for the front half of the project prompting consideration that material costs may be an unruly influence. Time forecasting (on this trial) presented an almost unrealistic project 'recovery' and this observation remained an important background consideration in future work as the behaviour highlighting the relationship between realistic planning and ES capacity to predict an outcome against such a base line. At this stage there was concern as to whether the forecasting could be stable enough to use in practice for these projects.

Taking advantage of the Sydney location of the research, a meeting was held between Henderson, a researcher who had worked with Lipke from early on in the Earned Schedule story, and the thesis author (Fox). The application strategies being used were discussed with Henderson, leading to some re-assurance that the approach as developed seemed at this time to be appropriate. Henderson also outlined past experiences with material costs and their influence on EV / PV curve separation, suggesting performing trials without materials should be included. He also discussed investigations being done using repeatable PV / ES curves for known products as a strategy for supporting project risk management during tendering and project planning (2009).

Autumn 2010 presented an opportunity to essentially repeat part of project T001. The EVM setup for this project (identified as T003) was similar to T001 but presentation of the worksheets and instructions for use had been improved since the 2009 trials. The approach taken for this project was to pass the data entry to the project engineer (PE) after some initial one-on-one training. Early effort and dialogue between the PE and researcher identified the modelled schedule slippage at the project's front end represented by the ES curve would be problematical if the tool is to be used for reporting externally. In short, the deviation between PV \& EV was not really reflecting the critical path which is the 'thing to watch' (Jacob \& Kane 2004) when making decisions about reporting project slippage with EV, particularly at this early stage of the project where the schedule's network is more parallel than serial (Vanhoucke \& Vandevoorde 2007). Reasons for this response were considered at the time as being either the influence of materials or skewed scheduling rather than poor progress as such (these matters are discussed more detail in Section 4.4.4). Through this trial there was also a suggestion to reduce the level of detail down further to perhaps just major milestones to help simplify its use. While overall the method received positive response in theory the realities of the required administration effort quickly eroded participation as workloads increased for the participant.

Balancing the need to allow the PE to focus on more pressing time-dependent manufacturing issues, the EVM data entry was taken-up by the researcher. At this stage user participation was not strongly pushed because system development was still immature and data streams although flowing still required management effort to ensure conformity and address system modification as required. It was also found that while the data entry of the PE was correct, commentary associated with EV allocation was not forthcoming, and this was an important 'data capture' exercise in this trial stage to understand allocation strategies and difficulties.

In parallel to T003 being setup and initially monitored, the forecasting calculations were refined into a form that allowed better interpretation than earlier efforts. As the project progressed and initial curve noise subsided, ES forecasting outputs were compared to the 'gut feel' forecasts of the PE which were made in isolation from ES forecasts. It was pleasing to see results from the last $50 \%$ of the duration of the project were showing correlation to the 'experience' based predictions. These results added confidence that the setup and application of the method was generating useful outcomes.

As a final investigation, a series of datasets (generally termed ' S ' Series) were prepared (specifically identified as S 001 to S 007 ) using a repeat project where a pair of simple vessels were manufactured. This data set provided an opportunity to observe the same TPB setting being re-run several times over, providing opportunity to observe the different outcomes that presented for the same project. The value in this exercise was the chance to eliminate the variability that projects (being typically a unique undertaking) were bringing to the testing ground and to allow the manufacturing variable to be observed through the EVM data. Using the more consistent base line this project series offered, the earlier suggestion by Henderson (p.77) relating to trialling labour only was applied at this point. These tests provided an opportunity to compare material \& labour with the labour only curves while keeping all other project variables consistent except for the manufacturing circumstances.

### 3.4.4 EVM Validation

Due to spread sheet modifications for trial T003, particularly in regard to forecasting, it was decided a review of the calculations and methods needed to be done as a 'sanity check' that the spread sheets were processing data correctly. To commence the checking, data from project T 001 was run through the latest spread sheets to review forecasting outputs against the known project performance as a means of validation. Testing re-produced previous T001 curves from earlier spread sheet versions and similar forecasts to T003. From the $50 \%$ complete mark the trends were suggesting reasonable correlation between the prediction and the actual end date achieved. At this point the method's adaption (with respect to data input and calculations) was considered sound. A fourth trial project (T004) was then setup as a final validation check for the methods adaption and also the researcher's understanding of input requirements. Results from this trial reflected the project behaviour as it progressed through the manufacturing phase, however (like project T002) the recovery in the final few weeks suggested there were potentially issues between scheduling culture and the reality of project execution in some cases, i.e. an unrealistic base line which ES was graphically representing as the reality.

Data entry and use of EVM / ES outputs for project T004 were completed after project execution. This strategy had been adopted as it was now recognised that preserving the 'normal' project flow through the manufacture cycle was an important element of the raw EVM data capture process. Virgin data regarding the fabrication time line was seen as critical to improving scheduling culture and hence how EVM forecasting may perform in the future.

It was also necessary to focus on simplifying the setup and addressing the administration effort. Therefore from this point forward effort was switched from live use to project data capture and re-producing project outcomes through modelling against real data sets.

Following an extensive re-vamp of the spread sheets in mid-2011 to simplify use and to expand the forecasting methods for comparison purposes as discussed further in Sections $3.4 .5 \& 3.4 .6$ respectively, a second validation run was completed with project T005 \& T001 data. Comparisons were made against earlier T001 curves which generally followed the pervious outputs. T005 was reviewed against raw data and actual outcomes as a check of the revised methods. In addition data was set to $\mathrm{EV}=\mathrm{PV}=\mathrm{AC}$ to confirm $100 \%$ conformity, a consistent cost overrun and EV lag were also run to check outputs were behaving as expected. The spread sheet calculations have since remained fixed for the duration of the research.

### 3.4.5 System Simplification

It was necessary to improve the front end of the EVM workbook so project information would be easily located and flow where possible into the EVM calculations as a means of addressing one of the administration issues observed in the trials. This was achieved by consolidating various spread-sheets into a single Excel workbook that covered different phases of the project from setup through to capturing execution tasks such as buying, modelling labour for EVM and analysing. A descriptive summary of the final project workbook sheets is presented in Table 3.1 below and the workings are discussed in detail in Section 4.2.

| Project Workbook Summary |  |
| :--- | :--- |
| Worksheet Title | Purpose |
| Job sheet | Capturing basic project information, used for <br> project communication with the workshop \& non- <br> project staff |
| Report | Summary of the projects financial and time <br> performance outcomes for project review |
| Payment Sheet | Instruction sheet for projects, contracts and <br> accounts outlining agreed payment terms and <br> values |
| Project Budget | The tool used to prepare the BAC, management |


| Project Workbook Summary |  |
| :---: | :---: |
| Worksheet Title | Purpose |
|  | reserve, overhead and net profit targets |
| Booked Hours | Entry sheet for direct work shop hours in weekly blocks |
| Plot of Hours | Graphical output of the project's labour profile \& cumulative booked hours |
| Material Cost | Entry field for purchasing to record buying costs and allocation of project expenses to the BAC |
| Labour for Time Phased Budget | Worksheet to compress the schedule's WBS activities into manageable work packages |
| Time Phased Budget | Work sheet for disturbing the budget across the schedule time and also calculates all EVM / ES and forecasting data |
| S Curve | Displays the outputs from the TPB worksheets for PV, EV, AC \& ES |
| IEAC ${ }_{\text {t }}$ | Displays the schedule forecasting output from the TPB worksheet |
| EAC | Displays the cost forecasting outputs from the TPB worksheet |

Table 3.1 - Descriptive Summary of the Project Workbook

Assembly of this workbook enabled linking between worksheets so data entry was reduced. Prior to this the same information needed to be entered several times across several workbooks. Although maintaining isolated workbooks and linking between them was an option, global conformity to file name conventions and locations presented issues in regard to user flexibility, system stability and effort. Over several development cycles material and labour data entry for the EV fields on the TPB worksheet were automated by using raw data values from their respective worksheets and distributing them based on the project week in which labour or material delivery had occurred. This approach reduced the EVM effort down to entry of the labour into the labour sheet and adding the project week when materials were received, (material values and other relevant details having been entered by the project buyer at the time of purchasing).

The most significant issue that had come to light over the trials was the reliance on the researchers manufacturing knowledge to compress and distribute the project's work
breakdown structure (WBS) into the TPB. This 'experience' requirement also extended to an element of judgment regarding allocation of the PV into the EV for the labour component as progress was achieved. In addition to this, the transfer of estimated labour value into discrete project activity effort also needed to be resolved. The 'judgment approach' used to covert estimated hours and their contingency factor into project deliverables was recognised as not only an administration burden but also a system element that required consistency regardless of the user. Under the trials scheme it was possible different value weights could be assigned to the same activity type by various users, therefore outputting different EV results. To summarise there were three issues to address regarding simplifying and improving the system for labour distribution and allocation:

- Improving system setup by establishing a link between the project schedule and the quoted labour $\rightarrow$ assigning a relevant PV to the TPB;
- Compressing the schedule $\rightarrow$ providing a logical set of discrete activities for the TPB; and
- Reducing effort and adding consistency to monitoring $\rightarrow$ allocation of the PV to the EV.

The problem of transforming quoted hours into planned value was simplified by reducing the problem down to its basic inputs and output. The estimate provided what was considered a lump-sum dollar value, while the schedule offered a series of activities and respective duration values for each. Therefore it was necessary to devise a method for distributing the total labour value across the numerous schedule activities. Using activity duration as a measure of labour value, a dollar value could be assigned pro-rata based on the total labour value and the total schedule (activity) duration. This approach eliminated the need to make a judgment about the value of an activity with respect to the project's total estimated labour scope.

By assigning values to scheduled activities the schedule compression problem was also simplified by the fact that during this process key WBS activities were extracted from the schedule for allocation. By further rolling up these individually selected activities, after allocation of labour, into work packages (WP) the compression along with a value was presented for the TPB. WP values were then entered into the TPB based on the project week in which they were planned to occur. In developing this approach consideration was given to
balancing 'administration burden' vs. WBS levels (Jacob 2003; Jacob \& Kane 2004) and the work of Vanhoucke \& Vandevoorde discussed in a series of short articles (2007-2008, 2008; 2009) summarising their wider research work on modelling and forecasting.

The effort applied in allocating and compressing the schedule was used to simplify the data entry of the EV by adding the project week data in which an activity occurred to the relevant activity information on the 'labour for TPB' worksheet. This was a simpler task that addressing EV on the TPB itself as the user was presented with a list of descriptive activities that had relevance to project scope rather that the rolled up WP's listed on the TPB with an overall value. Using the assigned week in the 'labour for TPB' the TPB EV cells were able to 'lookup' the week and assign values accordingly, therefore eliminating the need to manually enter correct activity values into the correct EV cells.

Overall the effort to generate EVM outputs had been reduced to a level that was considered acceptable for attempting to test and apply EVM to the live project environment. It needs to be acknowledged here that work within this research had developed the spread-sheets so as to distribute values for materials based on a pro-rata of the total expense relative to the budgeted value, to suit the post project analysis strategy being used for research. However to go 'live' the process used for allocation and distribution of labour values could be adapted to the material values using budgeted value and planned purchases. Further consideration of this development is discussed in concluding comments (Section 6.4) as commercial software platforms are a consideration in taking this application further for the host organisation.

### 3.4.6 Forecasting Strategies

EVM development presented problems that required solutions relating to user input, distribution of allowances and generally addressing matters relating to using the method in a specific project environment. Forecasting on the other hand is a process embedded in EVM, so once the method had been established in operation forecasting development decisions related to trialling on the same data sets began. Discussions towards the end of Section 2.3 explored the subject of forecasting and its status from a modelling perspective. Discussions here outline the cost and schedule forecasting methods built into the trials, details on specific formula included in the comparisons are discussed further in Section 4.4.3. Information from the literature review revealed many forecasting formula variants and it was apparent costrelated models were considered more stable than their time-related counterparts. In
developing the approach to forecasting it was decided to include several methods from each domain as part of the EVM data set outputs.

Forecasting methods included in these calculations were based on the PMI Practice Standard for EVM (2005) ${ }^{16}$. Some variants were added to explore specific aspects of a method where it was considered there may be value in having additional data outputs, such as varying running averages. The time domain calculations $\left(\mathrm{IEAC}_{\mathrm{t}}\right)$ were essentially based on the PMI method but substituted terms such as EV for ES in these formula, as had been developed by Likpe and Henderson in earlier work were included.

The resulting outputs consisted of a master IEAC ${ }_{t}$ work sheet presenting data with respect to project duration in the vertical axis and report dates (or percentage complete) in the horizontal axis. A similar master EAC worksheet was also prepared representing project value in the vertical axis and report time (or percentage completed) in the horizontal. Additional plots for both $\mathrm{IEAC}_{\mathrm{t}}$ and EAC were made to check the effect of the variants added. Adjustment to CPI or $\mathrm{SPI}_{\mathrm{t}}$ weightings could then be made to the variable forecasting calculations based the most favourable outputs of these variants. This was done to be able to illustrate the best weighting setting for the forecasting curves of that particular trial, information that was potentially a useful addition to the standard fixed forecasting formula also present in the outputs.

As there was some lag between the first trial and the final development of these forecasting curves all project data was entered into the latest spread sheet and provided the research with a consistent series of datasets and results for comparison. A full review and analysis discussion is included in Chapter 5.

### 3.5 Chapter Summary

As a precursor to the main research program, it was necessary to design and implement an adequate Project Management System (PMS) at the host organisation. This was a major exercise given the need to reconcile EVM data requirements with the imperatives of the accounting and business management systems while still affording some flexibility to the

[^11]project engineering role. Ultimately, a Project Management Office was instituted within LAP. The research intends to make a qualitative assessment of the change in project management difficulties at the host organisation following establishment of the PMS (H1 $1_{(\mathrm{PMS})}$ ).

The PMS provides the foundation for the second element of the research scope: investigation of the application of Earned Value and Earned Schedule to manufacturing projects at the host organisation. The design of the research is aligned to LAP's desire to improve project management using EVM as appropriate to support the process.

Having regard to this, the EVM questions to be investigated were centred on finding a practical approach to accessing EVM's monitoring and forecasting capacities and on seeking the optimal design for modelling project base lines for utilisation in EVM processing. In selecting the type of manufacturing projects to target for testing of EVM a need was seen to focus on products that were not excessively complicated to model but which nevertheless form an important component of the host's business. In the result it was decided to focus trials on pressure vessels, a regularly recurring project at LAP.

Research questions necessarily flow from the objectives of the research but have also been framed to deliver informative outcomes to the host organisation and its industry sector. Essentially the four EVM-related hypotheses ( $\mathrm{H} 1_{(\mathrm{EVM})}$ to $\left.\mathrm{H}_{(\mathrm{EVM})}\right)$ explore adaptation of EVM to see if it can deliver tangible benefits in the manufacture of heavy pressure equipment in an SME setting.

Initial trialling of EVM with a suitable project quickly showed that issues of frequency (sampling rate) and the level of detail (granularity) had profound - and sometimes divergent - implications for the effort needed to support the system and for the utility of outputs. It also underscored the challenges arising from changes in project scope, a common occurrence in this industry.

The desirability of doing some trialling both with and without including the value of materials was identified as potentially important (Section 3.4.3, p.77). Trials were also run on a sequence of identical repeat projects ( S 001 to S 007 ) to allow the effects of operational and environmental variables to be scrutinised.

Considerable effort was put into refining and simplifying data collection and entry processes - particularly in automating the distribution of total labour value across numerous schedule activities.

In relation to forecasting, many variant formulas had been found in the literature. It was decided to include several from both the time and cost domains in the trials to identify the most reliable and accurate formulas for this application.

## CHAPTER 4

## 4 Application and Data

### 4.1 Data Capture

Information needed for EVM analysis was dependent on three streams of data: direct labour valve, direct project costs and fabrication progress with respect to time. It should be noted that the host business at the time of this research did not have an ERP system in place so there was no central company data pool to draw the required information from, requiring the research to build up satisfactory processes to suit EVM and the business itself. In addition costing models for the organisation were vague and not clearly definable with respect to direct and indirect cost contributions requiring some initial assumptions to be made regarding how these were to be distributed into an EVM budget structure as discussed further in Section 4.2.2. Aspects of indirect project labour and allocation of these to the TPB through the valuing of discrete engineering and quality deliverables was highlighted in Section 1.6.2. In monetary terms the value of these elements are not really of significance to the EVM calculations being a small proportion of total project costs. However engineering deliverables are important to the critical path, a relationship that warrants emphasis and is therefore addressed further in Section 4.4.4.

Returning to the issue of the data stream for direct labour, a capture of this (per project) was an existing process embedded in the accounts function of the host business. To enable easy access to this information, improvements in the interaction between Accounts and Projects required a redesign of the record keeping process and its presentation. These organisational changes enable direct hour data worked on all projects to be accessible and easily transferred into a weekly block required for EVM calculations where it was converted to a dollar value using company cost rates.

Direct project costs consisted of materials and sub-contracting services, to keep the process simple. Purchasing data was entered into the project's workbook (Section 3.4.5) by the purchaser at the time of placing orders. Due to the need for purchasing information to flow into EVM calculations in a timely manner, the processes relating to this function needed to be definitively established from an organisational perspective. Tighter controls over order
details, filing, transparency of order value, issue date and expected delivery date were identified as important front end data for EVM. The project workbook concept played a large part in delivering a tightening of these controls and fitted well with the organisation's buying function. Developing processes to systematise purchasing seemed a more difficult task than extracting buying information from Accounts through supplier invoicing streams. However the overall goal of implementing a project management system required improvements in the purchasing process of the organisation as part of the broader application strategy being taken from literature. In addition, the lag between project activities and Accounts actually processing financial data made the option of using their data problematical. Accounts data issues were further compounded by the lack of specific purchasing detail available in a purely financial system.

Capturing fabrication progress became the most significant data 'capture' issue. This was due to its dependency on time. Unless effort is made to record progress as it actually occurs, the functioning of EVM can be compromised. To overcome the workload of managing a project while recording data from a research perspective for later entry into EVM, the solution was to use photos and establish a chronological visual library of manufacturing activities that capture the projects time line. Realising the potential of this data for not only this research project but the opportunity to bank non-retrievable data for future work, photos were taken most working days of all project activities occurring at the host's site. Over this period thousands of photos capturing fabrication activities became available for the organisation. Interestingly, as awareness grew in the organisation that there was a visual record of manufacturing; other functions began to use the information to improve their processes, capture lessons learnt and transfer knowledge to new staff. Consequently, the practice of visually recording project status regularly has become an essential part of the project management and quality systems.

### 4.2 Application Method

Previous discussion on application (Section 2.2.7) related to EVM's fit into the broader aspects of managing projects in an organisation and its use at varying levels of the WBS. Application under this section relates to the specific details of how EVM requirements were applied to the processes of the host organisation and the projects investigated. Each of the major elements that made the 'application' possible are discussed in detail below.

### 4.2.1 Project Work Book

A description of the project workbook was presented in Section 3.4.5. Individual worksheets that have specific relevance to EVM application are: project budget, booked hours, material cost, labour for the TPB and the TPB itself. Each of these sheets manipulates raw project data into a form that is usable in EVM and also supports other uses for the data by the organisation. A narrative of each of these worksheets is presented in the following sections, discussing the basis from which it was created and how it is used to support or generate EVM outputs. In addition, the project schedule (Gantt chart) plays an important role in the application process and therefore aspects of its characteristics are included in the following discussions (Section 4.2.5).

### 4.2.2 Project Budget

The Project Budget (PB) ${ }^{17}$ and Budget at Completion (BAC) definitions and structure were modelled using the guide-lines offered in AS4817 (Standards Australia 2006). The Australian Standard was initially selected because of its regional relevance to the research and the organisation with respect to its ISO 9001 accreditation where Australian standards were used in system compliance. Fortuitously it was found the simple definitions offered by this Australian standard provided an informative guide to project and business costs and their placement within the different budgets as presented by this standard. The PMI practice standard for EVM (2005), current at the relevant time, was also consulted but did not offer information to help understand the break-up of organisational costing for project budgets. The resulting budget structure provided the organisation with a tool that clearly allocated funds to project activities groups, overhead contribution, management reserve and profit. A descriptive outline of the adopted BAC and overall project budget is provided in Table 4.1 below followed by Figure 4.1 showing the 'BAC Group' user interface within the project budget (sample data is included and used throughout this section to assist in describing the application methods used).

[^12]| Description of Budget Elements | Planned Cost |  |  |
| :---: | :---: | :---: | :---: |
|  | \$/Unit | Description | Allocation |
| Total of eleven rows are provided for | 1 | BAC Group 1 Variable Material \& Services | $\begin{aligned} & 0 \\ & 0 \\ & 0 \\ & 0 \\ & 0 \\ & 0 \\ & \vdots \\ & \stackrel{0}{0} \\ & .0 \\ & 0 \end{aligned}$ |
| variable material and services groups | V |  |  |
| Four rows provided for fixed services | ! | BAC Group 2 Fixed Services \& Consumables |  |
| and consumable expenses | V |  |  |
| Four rows for covering; direct labour | ! | BAC Group 3 Labour |  |
| Engineering, QA effort \& contract mgt | V |  |  |
| Budget at Completion (BAC) | BAC/unit | Project Cost |  |
| Overhead Contribution (OH) | OH/unit | Indirect Cost | Company |
| Management Reserve (MR) | MR/unit | Risk Margin | Contingency |
| Planned Net Profit (PNP) | PNP/unit | Benefit | Profit |
| Project Budget (PB) | PB/unit | Total Value | Contract |

Table 4.1 - Project Budget Structure

| Cost Description | Cost / unit | Cost / Project | Notes |
| :---: | :---: | :---: | :---: |
| Heads Blanks | \$4,650.00 | \$9,300.00 |  |
| Head Forming | \$3,920.00 | \$7,840.00 | $\leftarrow$ |
| Shell Plates | \$7,850.00 | \$15,700.00 | $\stackrel{\Psi}{\Psi}$ |
| Profile, Section \& Misc | \$410.00 | \$820.00 | $\cdots$ |
| NDE \& Testing | \$2,000.00 | \$4,000.00 | $\stackrel{\square}{0}$ |
| N/A | \$0.00 | \$0.00 | $\stackrel{\square}{4}$ |
| Fasteners | \$80.00 | \$160.00 | 7 |
| Gaskets | \$60.00 | \$120.00 | \% |
| N/A | \$0.00 | \$0.00 | - |
| Painting | \$3,350.00 | \$6,700.00 | 8 |
| Heavy Transport | \$800.00 | \$1,600.00 | $\bigcirc$ |
| Transport to Site | \$0.00 | \$0.00 | $\stackrel{\square}{\stackrel{1}{0}}$ |
| Misc (Int Delivery, name plate etc) | \$80.00 | \$160.00 | $\sim$ |
| Shop Consumables \& Hydro | \$100.00 | \$200.00 | $\bigcirc$ |
| Contracted PWHT | \$0.00 | \$0.00 | 入 |
| Direct Labour Cost | \$9,000.00 | \$18,000.00 | 들 |
| QA Allowance | \$0.00 | \$0.00 | $\stackrel{Z}{\leftarrow}$ |
| Engineering, Design \& Draft | \$0.00 | \$0.00 |  |
| Commercial BG, Fees, Bid, Meetings | \$0.00 | \$0.00 |  |
| Budget at Completion (BAC) | \$32,300.00 | \$64,600.00 | I to Spend |

Figure 4.1 - Sample BAC user Interface

Through trials it was found necessary to provide a set of fields in the BAC that allowed customised input for material and services to suit each project (BAC Group 1). A series of services common to all projects was also recognised which lent themselves to a fixed description approach (BAC Group 2). Data entry options are illustrated by the tinted cells (tan colour). The final group of fields identified was associated with human effort being; shop labour, engineering and quality management (BAC Group 3). Development of this three tiered group of fields was an important step in adapting EVM, however determining the content and the quantity of fields provided within each of these BAC groups required significant integration with estimating, projects and purchasing to determine the number of variable fields to be available as well as what fixed description fields were required. Over the course of the research the number of fields has stabilised to the quantities shown in Table 4.1.

The three remaining fields of company, contingency and profit were simple enough to identify, Net Profit was taken directly from the estimators 'quote work sheets' and did not pose difficulty in identifying a value, however determining overhead contribution and management reserve was not as forthcoming. The overhead contribution field required agreement between the EVM cost model and the organisations regular accounts to ensure the fixed cost per hour, assigned to the projects estimated hours, contributed enough to the company's operational costs. 'Contingency' calculations are used to simplify the system's user effort by displaying a value that balances the contract value after subtracting the; BAC, overhead contribution and net profit. Using contingency as a balancing cell enables rounding errors and any modest unsubstantiated discounting, which may have occurred during tender negotiations, to be absorbed by the budget tool.

It is interesting to note that in the development of the budget and testing its flexibility for different project scenarios it was found that the suggestion by Kim, Wells \& Duffey to build flexibility "within a framework of general guideline" (2003, p. 380) had proven to be beneficial. Once established, the flexibility offered by this approach made the actual application of this budget a simple process and has resulted in it becoming a standard practice for the organisation on all projects. It is now applied even to projects that are considered too small for EVM. (These are identified as 'jobs'). The reason for the budget's broad uptake is in part due to its interaction with other functional managers outside the direct project management process and in particular the cost performance and feedback it delivers for estimating and contract management.

### 4.2.3 Booked Hours

Direct labour hours are entered into project specific time sheets daily by Accounts, the data is then transferred to the 'booked hours' worksheet where it is rolled up into weekly blocks. Although processing of this data is a simple exercise the development of the 'weekly block' concept provided a basis for understanding the frequency rate (Project Management Institute 2005, p. 4) and therefore how project measures could be broken up into various time segments to assess EVM's sensitivity to changes in actual progress. Clarification in defining the start point for the projects measurement periods also came from the work done in shaping the direct hours data stream. Using the 'order received' date as the start of week one of the project's weekly labour block it established a common week one for all subsequent data streams. Again this was a simple aspect of application but its definition became important as data stream manipulation converged to the TPB requirements. The other function this spread sheet serves is the conversion of hours into weekly costs for labour and the cumulative labour value over the project life. Setting labour data into weekly blocks also provided an opportunity to plot the weekly and cumulative labour at a frequency that later became important from an operations management perspective. These visual representations of labour profiles became a useful tool in being able to better understand direct labour effort within the project life cycle. Organisational benefits from this data process are discussed further in Section 5.12.2, p.193. An example for the 'Booked Hours' worksheet and comments on use are presented in Figure 4.2 below for reference.

| Reporting Scale <br> Report\# <br> (Project Weeks) |  |  |  | Year Week | Report Date | Prom |  | Hours Inclusive |  | Cost |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0 | 21 | $21 / 5 / 10$ | $14 / 05 / 10$ | $20 / 5 / 10$ | 0 | 0 | Weekly | Cumulative |  |  |  | Weekly | Cumulative |
| :---: |
| 1 |

Figure 4.2 - Booked Hours Worksheet Sample

As in the previous figure, tanned areas represent fields for data entry by the user. Reading data from earlier project workbook sheets the report date and period dates are automatically prepared for use, simplifying user input. Entry of weekly hours is manually done by summing data in the time sheets for the period in question, presently this task is not posing too great an administration issue for users because it is a simple process. This type of data entry, although simple remains a process that would benefit from further automation but is dependent on how the organisation chooses to take EVM application beyond this research as discussed further in Section 6.4.

### 4.2.4 Material Costs

Purchasing details for materials and services are entered into the project workbook's 'material costs' worksheet by the purchaser at the time when the order is placed. The worksheet performs three functions, firstly collecting buying data and assigning the value to a material group, secondly recording planned and actual dates and the respective project week the activity occurs. The final function (although currently specific to post processing project data for this research) has the task of allocating values to the EV cells in the TPB. Each of these data processing functions is discussed in the following text using examples of a complete worksheet to visually support the descriptions provided.

## Stage 1 - Collecting Buying Data \& Assigning to Material Groups

| Supplier | Description | PO | PO Costs | Ordered <br> Date | Cost Cell |
| :--- | :--- | ---: | ---: | :---: | :---: |
| APVH | Head blanks | PO 00940_1 | $\$ 8,504.00$ | $28 / 02 / 12$ | 1 |
| APVH | Forming ends | PO 00967_1 | $\$ 9,400.00$ | $5 / 03 / 12$ | 2 |
| Southern | Shell plate | PO 01031_1 | $\$ 17,378.00$ | $21 / 03 / 12$ | 3 |
| Southern | Manway rings | PO 00968_1 | $\$ 724.00$ | $5 / 03 / 12$ | 4 |
| Industrial Gaskets | Manway gasket | PO 00971_1 | $\$ 130.00$ | $5 / 03 / 12$ | 8 |
| Southern | Round \& flat bar | PO 00964_1 | $\$ 117.00$ | $2 / 03 / 12$ | 4 |
| RGA | Fasteners | PO 00956_1 | $\$ 142.00$ | $2 / 03 / 12$ | 7 |
| IMP | Painting vessel A | - | $\$ 3,500.00$ | - | 10 |
| IMP | Painting vessel B | - | $\$ 3,500.00$ | - | 10 |
| Wards | Name plates | - | $\$ 133.00$ | - | 13 |
| K\&W | LAP to APVH, Blanks | - | $\$ 800.00$ | - | 11 |
| K\&W | APVH to LAP, Heads | - | $\$ 750.00$ | - | 11 |
| K\&W | LAP to IMP, Vessel A | - | $\$ 500.00$ | - | 11 |
| K\&W | LAP to IMP, Vessel B | - | $\$ 500.00$ | - | 11 |
| Sonix | Vessel A (NDE on long seams) | PO 01200_0 | $\$ 2,954.00$ | $2 / 05 / 12$ | 5 |
| Sonix | Vessel B (Completion) | PO 01250_0 | $\$ 3,246.00$ | $14 / 05 / 12$ | 5 |
| Shop | Consumables | STOCK | $\$ 200.00$ | - | 14 |

Figure 4.3 - Material Costs Worksheet

The above blue tinted columns represent the buyer input fields. Some details such as supplier, PO (being the order number) and the order dates are not necessary for EVM calculations.

However the central information panel presented by this worksheet has become a reference point for a project's procurement. As a result the worksheets use from an organisational perspective has evolved beyond its initial EVM research scope to become an important tool for numerous other functions of the business. Therefore these additional non EVM fields contribute to accessing purchasing information in the absence of an ERP tool.

The cost cell column is used to allocate individual purchases to a material or service 'BAC Group' (being number one or two) as discussed in the project budget section (4.2.2) and illustrated in Table 4.1. This allocation is an important element for the overall project management system as it collects buying cost data and sums their value against estimated material packages. A completed sample of the cost cell and its associated project budget descriptions (material packages) showing the rolled up buying cost vs. budgeted is presented in Figure 4.4 below.

| Cost Cell | Description | Actual Cost | Budget |
| :---: | :--- | ---: | ---: |
| 1 | Heads Blanks | $\$ 8,504.00$ | $\$ 9,300.00$ |
| 2 | Head Forming | $\$ 9,400.00$ | $\$ 7,840.00$ |
| 3 | Shell Plates | $\$ 17,378.00$ | $\$ 15,700.00$ |
| 4 | Profile, Section \& Misc | $\$ 841.00$ | $\$ 820.00$ |
| 5 | NDE \& Testing | $\$ 6,200.00$ | $\$ 4,000.00$ |
| 6 | N/A | $\$ 0.00$ | $\$ 0.00$ |
| 7 | Fasteners | $\$ 142.00$ | $\$ 160.00$ |
| 8 | Gaskets | $\$ 130.00$ | $\$ 120.00$ |
| 9 | N/A | $\$ 0.00$ | $\$ 0.00$ |
| 10 | Painting | $\$ 7,000.00$ | $\$ 6,700.00$ |
| 11 | Heavy Transport | $\$ 2,550.00$ | $\$ 1,600.00$ |
| 12 | Transport to Site | $\$ 0.00$ | $\$ 0.00$ |
| 13 | Misc (Int Delivery, name plate etc) | $\$ 133.00$ | $\$ 160.00$ |
| 14 | Shop Consumables \& Hydro | $\$ 200.00$ | $\$ 200.00$ |
| 15 | Contracted PWHT | $\$ 0.00$ | $\$ 0.00$ |
|  |  | $\$ 52,478.00$ | $\$ 46,600.00$ |

Figure 4.4 - Material Cost Cells from the BAC Groups

In keeping with the theme of progressively developing an overall project management system for the organisation as part of the research program, processed data from this 'material cost cell' section of the worksheet is presented graphically as part of an overall project report and is illustrated in Figure 4.5 below.


Figure 4.5 - Material Cost Cell Reporting

## Stage 2 - Recording Planned \& Actual Dates

| Accounts | Scheduled <br> Delivery | Scheduled <br> Report \# | Actual <br> Delivery | Actual <br> Report \# |
| ---: | :---: | :---: | :---: | :---: |
| $\$ 8,504.00$ | $5 / 03 / 12$ | 2 | $7 / 03 / 12$ | 2 |
| $\$ 9,400.00$ | $3 / 04 / 12$ | 6 | $27 / 03 / 12$ | 5 |
| $\$ 17,378.00$ | $13 / 03 / 12$ | 3 | $29 / 03 / 12$ | 6 |
| $\$ 724.00$ | $13 / 03 / 12$ | 3 | $9 / 03 / 12$ | 3 |
| $\$ 130.00$ | $8 / 03 / 12$ | 3 | $6 / 03 / 12$ | 2 |
| $\$ 117.00$ | $2 / 03 / 12$ | 2 | $7 / 03 / 12$ | 2 |
| $\$ 142.00$ | $8 / 03 / 12$ | 3 | $9 / 03 / 12$ | 3 |
| $\$ 3,500.00$ | $23 / 05 / 12$ | 13 | $23 / 05 / 12$ | 13 |
| $\$ 3,500.00$ | $23 / 05 / 12$ | 13 | $23 / 05 / 12$ | 13 |
| $\$ 133.00$ | $24 / 05 / 12$ | 14 | $24 / 05 / 12$ | 14 |
| $\$ 800.00$ | $8 / 03 / 12$ | 3 | $9 / 03 / 12$ | 3 |
| $\$ 750.00$ | $3 / 04 / 12$ | 6 | $27 / 03 / 12$ | 5 |
| $\$ 500.00$ | $10 / 05 / 12$ | 12 | $15 / 05 / 12$ | 12 |
| $\$ 500.00$ | $10 / 05 / 12$ | 12 | $15 / 05 / 12$ | 12 |
| $\$ 2,954.00$ | $7 / 04 / 12$ | 7 | $25 / 04 / 12$ | 9 |
| $\$ 3,246.00$ | $2 / 05 / 12$ | 10 | $10 / 05 / 12$ | 12 |
| $\$ 200.00$ | $15 / 04 / 12$ | 8 | $20 / 04 / 12$ | 9 |

Figure 4.6 - Deliveries, Planned \& Actual Dates

The tanned fields in Figure 4.6 represent input by the EVM user / project personnel. Apart from the 'accounts' field, which is an optional field for checking account records against purchasing (again relates to not having an ERP system available) all fields are data needed for EVM to function. A brief outline of their data source and use is noted below under the headings relating to the respective columns.

Scheduled Delivery - Represents the date in which the goods or services were scheduled to be delivered as planned by the project schedule (Section 4.2.5)

Scheduled Report \# - Requires entry of the relative project week in which the material or services are scheduled for delivery (Refer to Figure 4.2 'Report \# (Project Weeks)' column for relevance of the data entered into this 'Scheduled Report' \# field.

Actual Delivery - Captures the date on which the materials or services were received. For consistency in measurement the date used in this field is the date on which items were booked in the store as accepted or services were agreed as complete. Information for this field is taken from the stores "Goods Received Register', a spread sheet completed by the LAP store person and available on the server for access. (Although the migration of this process to digital form was part of the research effort, details are not of significance to this discussion as development was related to quality assurance rather than EVM data acquisition.)

Actual (Delivery) Report \# - Requires entry of the relative project week in which the material or services were received using the date from the previous column to allocate the correct period number relative to the project reporting week scheme (Refer to Figure 4.2 for relevance)

## Stage 3 - Processing Data for the TPB Earned Value cells

The need to assign the BAC group material value to the earned value cells so the EV would equal the PV at the end of the project was a key driver for the development of this stage of data processing. Using a combination of data entry from the above processes and the material package values from the BAC Groups, the spread sheet performs a pro-rata of BAC's rolled up material package costs to calculate a representative 'budgeted value' for the individual purchase. This 'budgeted value' can then be distributed into the TPB - EV cells using the delivered 'Actual Report \#' data to allocate the 'budgeted value' to the correct project week the material was received. As previously discussed this process evolved as a result of wanting the specific EVM analysis to be run 'post project' so the 'normal' manufacturing event could be captured and not influenced by EVM slippage and forecasting indicators themselves causing an abnormal organisation reaction. Figure 4.7 provides an example of the cost cell and actual report fields provided with the output calculation used to achieve a 'BAC Group' representative 'budgeted value' to individual purchases for automatic population of the TPB - EV fields.

It is acknowledged that this method can only be used when re-modelling the project as purchases values are not known and as new orders are placed and assigned a cost cell, the additional purchase does re-distribute the BAC Group value. However from a research perspective it improved the data processing by eliminating the need to individually assign a proportion of the BAC Group value and manually entering this into the TPB - EV cells. The task of assigning dollars to the correct EV was not really a beneficial research activity. The value of this investigation was in being able to accurately model existing projects to observe how the method responded to the different cost and labour spikes that were present in these short duration projects. To run the material allocation method live would require some adjustment (as noted at the end of Section 3.4.5) to the calculation strategy, as automating the transfer of material EV (if it proved desirable to keep these values in the EVM calculations) is an important step in reducing the administration effort to run the system.

| Cost Cell | Actual Report \# | Cell Total Actual Cost | \% of cost | Item BAC Allowance | Share of Item BAC \$ | Rounded Item BAC \$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | 2 | \$8,504.00 | 100.00\% | \$9,300.00 | \$9,300.00 | \$9,300.00 |
| 2 | 5 | \$9,400.00 | 100.00\% | \$7,840.00 | \$7,840.00 | \$7,840.00 |
| 3 | 6 | \$17,378.00 | 100.00\% | \$15,700.00 | \$15,700.00 | \$15,700.00 |
| 4 | 3 | \$841.00 | 86.09\% | \$820.00 | \$705.92 | \$706.00 |
| 8 | 2 | \$130.00 | 100.00\% | \$120.00 | \$120.00 | \$120.00 |
| 4 | 2 | \$841.00 | 13.91\% | \$820.00 | \$114.08 | \$114.00 |
| 7 | 3 | \$142.00 | 100.00\% | \$160.00 | \$160.00 | \$160.00 |
| 10 | 13 | \$7,000.00 | 50.00\% | \$6,700.00 | \$3,350.00 | \$3,350.00 |
| 10 | 13 | \$7,000.00 | 50.00\% | \$6,700.00 | \$3,350.00 | \$3,350.00 |
| 13 | 14 | \$133.00 | 100.00\% | \$160.00 | \$160.00 | \$160.00 |
| 11 | 3 | \$2,550.00 | 31.37\% | \$1,600.00 | \$501.96 | \$502.00 |
| 11 | 5 | \$2,550.00 | 29.41\% | \$1,600.00 | \$470.59 | \$471.00 |
| 11 | 12 | \$2,550.00 | 19.61\% | \$1,600.00 | \$313.73 | \$314.00 |
| 11 | 12 | \$2,550.00 | 19.61\% | \$1,600.00 | \$313.73 | \$314.00 |
| 5 | 9 | \$6,200.00 | 47.65\% | \$4,000.00 | \$1,905.81 | \$1,906.00 |
| 5 | 12 | \$6,200.00 | 52.35\% | \$4,000.00 | \$2,094.19 | \$2,094.00 |
| 14 | 9 | \$200.00 | 100.00\% | \$200.00 | \$200.00 | \$200.00 |

Figure 4.7 - Material Costs Processed for TPB EV Allocation

### 4.2.5 Schedule

Project schedules (Gantt Charts) have long been an existing part of the organisation's culture, typically required by clients for projects of a size relevant to this investigation. As part of the EVM adaption process, preparation of preliminary scheduling was transferred to the now established project management office to initiate earlier planning than had occurred
previously. The importance of retaining normal practices was seen as a way of ensuring there was minimal disruption to the flow of work and to also be sure of capturing normal schedule methodology due to the dependency between EVM outputs and the schedule baseline.

The main components of these projects are relatively simple and identifiable, therefore suited to the work break down structure (WBS) process and discrete measuring function of EVM. Major elements can be aligned with the 'control account' concept (Project Management Institute 2011, pp. 32-3) being one of six accounts: engineering, quality assurance (QA), procurement, fabrication, testing / treatment and packing / dispatch. Through experience it has been found the accuracy of the overall project duration, represented by the schedule, benefits from further break down of these accounts into their work packages and subsequent activities when preparing a schedule.

In contrast to the simplicity of the main components and the finished product, the manufacturing 'build sequence' can become complicated as quality and access limitations constrain the process. As a result good product knowledge is required when preparing schedules. The practice of further breaking down of the work packages when scheduling has advantages in ensuring the project scope and build sequence is well planned in advance of manufacturing. For reference to the schedule methodology adopted by the organisation and hence what has been used by the research, all schedules for the projects represented by this research are included in Appendix A. Projects T001 and a typical 'S' series schedule are presented at the task level, the remaining schedules are rolled up to the WP level. For further clarity Figure 4.8 (included at the end of this section) illustrates the WBS structure of the schedule relative to the sample project used throughout Section 4.2 as a cross reference to relevant figures and tables.

The down side of this process though is it can create lengthy and complicated schedules, which tends to diminish its value as a communication tool for reporting progress to clients. Moreover it leads to difficulties in EVM application when assigning estimated labour costs to actual work package activities and scaling these to a suitable time phased budget. The solution to this problem was in part taken from the work done in proportioning actual material expenses to represent the BAC values as discussed in Section 4.2.4. Reasons for addressing the issue with respect to the system were initially discussed when addressing
'system simplification' (Section 3.4.5). Consolidation of these concepts and a detailed explanation of the solution are further outlined in Section 4.2 .6 below.

| ID | (1) | Task Name | Duration | Start | Finish |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 0 |  | Sample Vessel | 75.2 days | $\begin{array}{r} \text { Thu } \\ 23 / 02 / 12 \end{array}$ | Sat 26/05/12 |
| 1 |  | 1 Commercial | 4 days | Thu 23/02/12 | Tue 28/02/12 |
| 6 |  | 2 Material Procurement | 30 days | Sat 25/02/12 | Tue 3/04/12 |
| 7 |  | 2.1 Purchasing | 4 days | Sat 25/02/12 | Thu 1/03/12 |
| 14 |  | 2.2 Material Delivery | 25 days | Fri 2/03/12 | Tue 3/04/12 |
| 22 |  | 3 Fabrication | 42.4 days | Tue 6/03/12 | Fri 27/04/12 |
| 23 |  | 3.1 Nozzle Preperation | 9 days | Tue 13/03/12 | Sat 24/03/12 |
| 24 |  | 3.1.1 Maching \& drill manway flange | 4 days | Tue 13/03/12 | Mon 19/03/12 |
| 25 |  | 3.1.2 Roll manway neck | 1 day | Tue 13/03/12 | Wed 14/03/12 |
| 26 |  | 3.1.3 Weld long seam \& NDE | 3 days | Wed 14/03/12 | Mon 19/03/12 |
| 27 |  | 3.1.4 Fit flanges | 2 days | Mon 19/03/12 | Wed 21/03/12 |
| 28 |  | 3.1.5 Weld flange to neck cir seam | 2 days | Wed 21/03/12 | Fri 23/03/12 |
| 29 |  | 3.1.6 NDE seams | 1 day | Fri 23/03/12 | Sat 24/03/12 |
| 30 |  | 3.2 Fabrication of attachments | 24.2 days | Tue 6/03/12 | Thu 5/04/12 |
| 31 |  | 3.2.1 Fabricate external attachments | 5 days | Tue 6/03/12 | Mon 12/03/12 |
| 32 |  | 3.2.2 Fabricate internal attachments | 5 days | Tue 6/03/12 | Mon 12/03/12 |
| 33 |  | 3.2.3 Fit hold down bracket to heads | 2 days | Tue 3/04/12 | Thu 5/04/12 |
| 34 |  | 3.3 Shell Fabrication | 26 days | Tue 27/03/12 | Fri 27/04/12 |
| 49 |  | 4 Testing \& Surface Treatment | 19 days | Mon 30/04/12 | Wed 23/05/12 |
| 50 |  | 4.1 Testing \& Preperation | 8 days | Mon 30/04/12 | Wed 9/05/12 |
| 57 |  | 4.2 Painting | 11 days | Wed 9/05/12 | Wed 23/05/12 |
| 62 |  | 5 Final Inspection, Packing \& Transport | 3 days | Wed 23/05/12 | Sat 26/05/12 |
| 63 |  | 5.1 Final internal clean \& packing | 1 day | Wed 23/05/12 | Thu 24/05/12 |
| 64 |  | 5.2 Final inspection | 0 days | Thu 24/05/12 | Thu 24/05/12 |
| 65 |  | 5.3 Close off vessel | 1 day | Fri 25/05/12 | Sat 26/05/12 |
| 66 |  | 5.4 Delivery to Client | 0 days | Sat 26/05/12 | Sat 26/05/12 |

Figure 4.8 - Sample Project Schedule WBS

### 4.2.6 Labour for the TPB

Prior to developing the details of this phase of data preparation the number of TPB labour cells needed to represent a pressure vessel project had settled at nine labour work packages. For clarity these WP will be referred to as 'Work Description Cell' (WDC) to distinguish them from other work package related discussions. A sample of these WDC as they appear in the TPB worksheet is illustrated in Figure 4.9 below.

| TPB <br> WDC \# | TPB Manufacture <br> (Work Description Cells - Repesentation of the Labour Budget) |
| :---: | ---: |
| 28 | Pre-Fabrication - Nozzles |
| 29 | Pre-Fabrication - Attachments |
| 30 | Strakes - Roll \& weld strakes |
| 31 | Assemble - strakes \& end |
| 32 | Fitout - Nozzles \& internal attachments |
| 33 | Closing - End \& weld |
| 34 | Finishing - External attachments |
| 35 | Testing - Hydro test, dressing \& load |
| 36 | FI \& Pack - Dress \& close |

Figure 4.9 - TPB Labour WDC Sample

The activities listed in the WDC are reflective of the main fabrication tasks undertaken to manufacture a pressure vessel. Allocation has been approached by grouping the many scheduled activities into one of the nine WDC. This typically resulted in three or more scheduled activities representing a single WDC listed in the TPB. Labour values from the budget can then be transferred through a pro-rata method to the decompressed TPB - WDC fields. The process is done in two stages, the first being the decompression of the WDC using scheduled activities from the WBS within the schedule and assigning the duration value which is then converted to a dollar rate for EVM. The second stage re-compresses the schedule and rolls up the WBS task values into the original TPB - WDC descriptions. Figure 4.10 and Figure 4.11 illustrate the stage one and two respectively with the tanned cells again showing fields requiring user input.

| Schedule WBS | Schedule Activity | Days | TPB WDC \# | Breakout Cost |
| :---: | :---: | :---: | :---: | :---: |
| 3.1.1 | Nozzles - Machine \& drill manway flange | 4 | 28 | \$1,440.00 |
| 3.1.2 | Nozzles - Roll necks | 1 | 28 | \$360.00 |
| 3.1.4 | Nozzles - Fit flanges | 2 | 28 | \$720.00 |
| 3.1.5 | Nozzles - Weld flange | 2 | 28 | \$720.00 |
| 3.2.1 | Attachments - External | 5 | 29 | \$1,800.00 |
| 3.2.2 | Attachments - Internals | 5 | 29 | \$1,800.00 |
| 3.2.3 | Attachments - Lug for heads | 2 | 29 | \$720.00 |
| 3.3.1 | Strakes - Cut \& roll plates | 3 | 30 | \$1,080.00 |
| 3.3.2 | Strakes - Weld long seams | 3 | 30 | \$1,080.00 |
| 3.3.4 | Assemble - Strakes \& dished ends | 2 | 31 | \$720.00 |
| 3.3.5 | Assemble - Weld cir seams | 3 | 31 | \$1,080.00 |
| 3.3.6 to 3.3.8 | Fitout - Mark cut, fit \& weld manway | 3 | 32 | \$1,080.00 |
| 3.3.9 to 3.3.10 | Fitout - Mark, fit \& weld internals | 2 | 32 | \$720.00 |
| 3.3.11 | Closing - Fit closing end | 1 | 33 | \$360.00 |
| 3.3.12 | Closing - Weld cir seam | 2 | 33 | \$720.00 |
| 3.3.13 \& 3.3.14 | Finish - Mark, fit \& weld externals | 3 | 34 | \$1,080.00 |
| 4.1.2 | Testing - Dimensional | 1 | 35 | \$360.00 |
| 4.1.3 \& 4.1.4 | Testing - Hydro | 2 | 35 | \$720.00 |
| 4.1.5 \& 4.1.6 | Testing - Drain \& prep to transport | 2 | 35 | \$720.00 |
| 5.1 | FI \& Pack - Internal clean | 1 | 36 | \$360.00 |
| 5.3 | FI \& Pack - Close off vessel | 1 | 36 | \$360.00 |
|  |  | 50 | - | \$18,000.00 |

Figure 4.10 - Decompressing the TPB WDC for Task Allocation

| TPB Cell | TPB Activity | Days | \% of Total | Cost Allocation |
| :---: | :--- | :---: | :---: | ---: |
| 28 | Pre-Fabrication - Nozzles | 9 | $18.0 \%$ | $\$ 3,240.00$ |
| 29 | Pre-Fabrication - Attachments | 12 | $24.0 \%$ | $\$ 4,320.00$ |
| 30 | Strakes - Roll \& weld strakes | 6 | $12.0 \%$ | $\$ 2,160.00$ |
| 31 | Assemble - strakes \& end | 5 | $10.0 \%$ | $\$ 1,800.00$ |
| 32 | Fitout - Nozzles \& internal attachments | 5 | $10.0 \%$ | $\$ 1,800.00$ |
| 33 | Closing - End \& weld | 3 | $6.0 \%$ | $\$ 1,080.00$ |
| 34 | Finishing - External attachments | 3 | $6.0 \%$ | $\$ 1,080.00$ |
| 35 | Testing - Hydro test, dressing \& load | 5 | $10.0 \%$ | $\$ 1,800.00$ |
| 36 | FI \& Pack - Dress \& close | $\mathbf{2}$ | $4.0 \%$ | $\$ 720.00$ |
|  |  |  | $\mathbf{5 0}$ | $\mathbf{1 0 0 . 0 \%}$ |

Figure 4.11 - Re-Compressing the TPB WDC and Rolled up Cost

The process of converting the WBS activity durations into a representative value of the total estimated labour is automated by the spread sheet, for clarity the calculations are stepped out in Table 4.2 providing a tabulated example of how the method expands the WDC, assigns labour value based on scheduled work and then re-compresses it for easier use in EVM application. This approach secures representation of the schedule in terms of specific activities, their planned duration and maps this with a portion of the budgeted value for labour. The process has eliminated issues with earlier trials that required a reliance on user approximation it has also simplified the process of cost assignment to the TPB. Using this
method it is possible to compress a very detailed schedule from an extensive list of activities into the TPB's nine rows while maintaining a structure that has the necessary degree of logic to achieve system consistency.

| Schedule Information |  |  | TPB Data |  |
| :---: | :---: | :---: | :---: | :---: |
| WBS \# | Scheduled Work Activity | Unit Duration (days) | Work <br> Description Cell (WDC) | Assigned Value (AV) |
| 3.1.1 | Nozzles - machine... | 4 | 28 | 4/TSD x LB |
| 3.1.2 | Nozzles - roll necks | 1 | 28 | 1/TSD x LB |
| 3.1.4 | Nozzles - fit flanges | 2 | 28 | 2/TSD x LB |
| 3.1.5 | Nozzles - weld flange | 2 | 28 | 2/TSD x LB |
| ! |  |  |  | ' |
| ! | Attachments - external | 5 | 29 | , |
| ' | Attachments - internal | 5 | 29 | ' |
| ! | Attachments - lug... | 2 | 29 | , |
| V |  |  |  | V |
| 5.1 | FI \& Pack - internal... | 1 | 35 | 1/TSD x LB |
| 5.3 | FI \& Pack - Close off | 1 | 35 | 1/TSD x LB |
|  | Total Scheduled Days | TSD | Labour Budget | LB (\$) |
| Compressed TPB Activities |  |  | TPB Allocation Portion |  |
| WDC | TPB Activity Description | Sum of Unit Duration for cell | Duration for cell as \% of TSD | Value for Activity WDC |
| 28 | Nozzle fabrication | $4+1+2+2$ | 9/TSD | $\begin{aligned} & \text { Sum AV for } \\ & 28 \text { 's } \end{aligned}$ |
| ! |  |  |  |  |
| 29 | Attachments | $5+5+2$ | 12/TSD | $\begin{aligned} & \text { Sum AV for } \\ & 29 \text { 's } \end{aligned}$ |
| V |  |  |  |  |
| 36 | Packing | $1+1$ | 2/TSD | Sum AV for 36's |

Table 4.2 - TPB WDC Value Allocation Details

The final stage of labour allocation to the TPB is the actual distribution of the WDC values across the projects planned period (Setting the labour PV). There is then the need to distribute the values of activities within the WDC as they are accomplished, assigning them to the EV
cell in the TPB. This data entry was the most onerous task of maintaining or even post analysing a project in terms of EVM administration effort. By building onto the above WDC worksheet the task of dealing with fabrication activities within the TPB and its reporting week environment was eliminated by transferring this report allocation to the labour TPB Worksheet where project activities were the focal environment. The meant the data input was reduced to allocating weeks to activities instead of allocating value of activities to weeks in the TPB environment, this proved a much easier task and less prone to error. The extension to the Labour TPB worksheet is presented in Figure 4.12 below showing columns for entering the planned dates using the projects schedule and the completion date using the projects visual library (under the researchers post analysis method) or actual completion if used live. The appropriate project week is then assigned to the date in which the activity occurred, the week numbers are then read by excel and allocated to the PV and EV - TPB rows accordingly.

| Schedule WBS | Schedule Activity | Planned Start | Planned Finish | Planned Report \# | Actual Finish | Actual Report \# |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 3.1.1 | Nozzles - Machine \& drill manway flange | 13/03/12 | 19/3/12 | 4 | 2/4/12 | 6 |
| 3.1.2 | Nozzles - Roll necks | 13/03/12 | 14/3/12 | 3 | 5/3/12 | 2 |
| 3.1.4 | Nozzles - Fit flanges | 19/03/12 | 21/3/12 | 4 | 13/4/12 | 3 |
| 3.1.5 | Nozzles - Weld flange | 21/03/12 | 23/3/12 | 5 | 16/4/12 | 8 |
| 3.2.1 | Attachments - External | 6/03/12 | 12/3/12 | 3 | 4/4/12 | 6 |
| 3.2.2 | Attachments - Internals | 6/03/12 | 12/3/12 | 3 | 16/4/12 | 8 |
| 3.2.3 | Attachments - Lug for heads | 3/04/12 | 5/4/12 | 7 | 30/3/12 | 6 |
| 3.3.1 | Strakes - Cut \& roll plates | 27/03/12 | 30/3/12 | 6 | 3/4/12 | 6 |
| 3.3.2 | Strakes - Weld long seams | 31/03/12 | 4/4/12 | 6 | 5/4/12 | 7 |
| 3.3.4 | Assemble - Strakes \& dished ends | 9/04/12 | 10/4/12 | 7 | 13/4/12 | 8 |
| 3.3.5 | Assemble - Weld cir seams | 11/04/12 | 14/4/12 | 8 | 19/4/12 | 9 |
| 3.3.6 to 3.3 .8 | Fitout - Mark cut, fit \& weld manway | 14/04/12 | 18/4/12 | 8 | 3/5/12 | 11 |
| 3.3.9 to 3.3.10 | Fitout - Mark, fit \& weld internals | 18/04/12 | 20/4/12 | 9 | 5/5/12 | 11 |
| 3.3.11 | Closing - Fit closing end | 20/04/12 | 21/4/12 | 9 | 26/4/12 | 10 |
| 3.3.12 | Closing - Weld cir seam | 21/04/12 | 24/4/12 | 9 | 1/5/12 | 10 |
| 3.3.13 \& 3.3.14 | Finish - Mark, fit \& weld externals | 24/04/12 | 27/4/12 | 10 | 5/5/12 | 11 |
| 4.1.2 | Testing - Dimensional | 2/05/12 | 3/5/12 | 11 | 11/5/12 | 12 |
| 4.1.3 \& 4.1.4 | Testing - Hydro | 3/05/12 | 7/5/12 | 11 | 12/5/12 | 12 |
| 4.1.5 \& 4.1.1.6 | Testing - Drain \& prep to transport | 7/05/12 | 9/5/12 | 11 | 14/5/12 | 12 |
| 5.1 | FI \& Pack - Internal clean | 23/05/12 | 24/5/12 | 14 | 24/5/12 | 14 |
| 5.3 | FI \& Pack - Close off vessel | 25/05/12 | 26/5/12 | 14 | 25/5/12 | 14 |

Figure 4.12 - Labour TPB, PV \& EV Data Entry

### 4.2.7 Time Phase Budget

The design of the present Time Phase Budget (TPB) was achieved over approximately a 12 month period through trial and error on varying projects and achieving a format that suited the project activities. The main issue in developing its interface from an organisational perspective was achieving a balance in the number of fields, its interaction with the BAC and the project schedule (representing the work packages activities). The most suitable
arrangement for these fields resulted in a structure based on three main cost account inputs, being: Engineering / QA (the indirect labour contribution), Purchasing \& Subcontracting (the materials and services), Manufacturing (the direct shop labour). Significant simplification in preparing the TPB came from adopting the inputs of both BAC Group's $1 \& 2$ and applying them to the 'material and services' TPB fields. Other cost inputs are independent of the budget and require an allocation strategy that is customized to each project. Figure 4.13 illustrates the TPB cost cell groups used to represent the projects deliverables and the first three reporting weeks for the project. The tanned cells under the 'Activities from WBS' column being 'Engineering \& QA' and Manufacture (as discussed in Section 4.2.6) are customised to suit the project, while the 'Material \& Services' fields are populated directly by excel reading the descriptions from the BAC worksheet. At the time the research concluded the entry for the 'Engineering \& QA Effort' capturing the actual delivered value for EV calculation was still manual and represented by the tanned row near the bottom of the figure.

| Activities from WBS | February |  | March |
| :---: | :---: | :---: | :---: |
|  | upto 22/2/12 | 23/2 to 29/2 | 1/3 to 7/3 |
| Engineering \& QA |  |  |  |
| Design \& GA |  |  |  |
| External Details |  |  |  |
| Internal Details |  |  |  |
| Transport \& Lifting |  |  |  |
| QA/QC |  |  |  |
| Material \& Services |  |  |  |
| Heads Blanks |  |  | \$9,300 |
| Head Forming |  |  |  |
| Shell Plates |  |  |  |
| Profile, Section \& Misc |  |  | \$130 |
| NDE \& Testing |  |  |  |
| N/A |  |  |  |
| Fasteners |  |  |  |
| Gaskets |  |  |  |
| N/A |  |  |  |
| Painting |  |  |  |
| Heavy Transport |  |  |  |
| Transport to Site |  |  |  |
| Misc (Int Delivery, name plate etc) |  |  |  |
| Shop Consumables \& Hydro |  |  |  |
| Contracted PWHT |  |  |  |
| Manufacture (Work Description Cells - Repesentation of the Labour Budget) |  |  |  |
| Pre-Fabrication - Nozzles | \$0 | \$0 | \$0 |
| Pre-Fabrication - Attachments | \$0 | \$0 | \$0 |
| Strakes - Roll \& weld strakes | \$0 | \$0 | \$0 |
| Assemble - strakes \& end | \$0 | \$0 | \$0 |
| Fitout - Nozzles \& internal attachments | \$0 | \$0 | \$0 |
| Closing - End \& weld | \$0 | \$0 | \$0 |
| Finishing - External attachments | \$0 | \$0 | \$0 |
| Testing - Hydro test, dressing \& load | \$0 | \$0 | \$0 |
| FI \& Pack - Dress \& close | \$0 | \$0 | \$0 |
| Planned Value - Period ( $\mathrm{PV}_{\mathrm{P}}$ ) | \$0 | \$0 | \$9,430 |
| Planned Value - Cummulative (PV) | \$0 | \$0 | \$9,430 |
| Engineering \& QA Effort | \$0 | \$0 | \$0 |
| Actual Labour Cost | \$0 | \$0 | \$2,205 |
| Actual Material Cost | \$0 | \$0 | \$8,751 |
| Reporting date for the period | 23/02/12 | 1/03/12 | 8/03/12 |
| Report \# (Project Weeks) | 0 | 1 | 2 |

Figure 4.13 - Sample TPB Cost Cell Structure
Expanding on the explanation of these cell and their values Table 4.3 presents the above TPB fields in a descriptive context so as to clarify their relationship with the BAC and illustrate the built in flexibility while being contained within the boundaries on the cell range. Following this table, each of the cost accounts are further discussed providing details on development and application.

| Combined activities from the WBS \& BAC fields | Distribution of Dollars / Time |  |  |
| :---: | :---: | :---: | :---: |
|  | Week 1 | Week 2... | Week \# |
| Engineering \& QA (using engineering \& QA values from BAC Group 3 ${ }^{\text {18 }}$ ) |  |  |  |
| Five fields for independent input representing activities | \$ | $\ldots$ | Total \$ |
| Purchasing \& Sub-Contracting (using values \& field inputs from BAC Groups 1 \& 2) |  |  |  |
| Eleven fields from BAC - Variable materials \& services | \$ | \$ | Total \$ |
| Four fields from BAC - Fixed services \& consumables | $\ldots$ | \$ | Total \$ |
| Manufacturing (using shop labour values from BAC Group 3) |  |  |  |
| Nine fields for independent input representing build sequence activities | $\ldots$ | \$ | Total \$ |

Table 4.3 - TPB Cost Cell Descriptions

## Engineering \& QA field

Engineering \& QA field offers five rows for input and has been setup as an independent and flexible cell group. The work descriptions applied are designed to represent key activities within the schedules engineering \& QA deliverables, they can also carry across any administration allocations that may have been included in the budget. Flexibility was applied to this group because its contribution to the overall project budget is typically small and it was found the physical delivery of these activities were frequently not clearly definable in terms of 'being finished'. This is due to projects generally being executed under a concurrent engineering strategy which saw critical engineering completed to schedule while supplementary detail (not affecting progress) lagged for some time after the planned completion. Although the work in this field is best described as discrete effort, its entire completion is not a pre-requisite to achieving progress. For the purposes of applying EVM, the effort put into Engineering \& QA is typically assigned to tangible deliverables that directly affect progress and measured using a fixed formula of 0/100 (Project Management Institute 2011, pp. 36-8). This measure was selected because the critical deliverables from these departments typically only take one period to actually deliver but generally do have an impact if not received by the date. An example of this would be 'calculations and general arrangement details submitted'. The approach simplifies the allocation of earned value for the

[^13]user and is believed to realistically depict progress in an area that has an 'on and off' impact on manufacturing.

## Purchasing \& Subcontracting field

Purchasing \& Subcontracting field has been set up to display the activity descriptions entered into 'Groups $1 \& 2$ ' of the BAC. Unlike the engineering \& QA, material and service descriptions are established through interaction with the estimators quote work sheet and BAC , rather than the schedule content. As this field delivers a large portion of the projects budget it was considered important to limit flexibility and user input while increasing control over alignment between the budget and the time phasing fields. To simplify user effort it has been found materials are best treated as discrete effort and assigned $100 \%$ of their value on delivery into the factory, this allocation method is in line with the prescribed method of (Project Management Institute 2011, pp. 36-8). Services are considered as sub-contracted activities of tangible product. The value of these is typically high in proportion to overall material budget and usually extends over several measurement periods. Through several trials and taking user effort into consideration it was found the best means of allocation was using a weighted milestone as suggested in the (Project Management Institute 2011, p. 38) and dividing the budget value across milestones the contractor will achieve over the course of the work. A good example of the method's use is during painting, where there is a blast and prime phase (40\%), top coat (40\%) and final inspection (20\%).

## Manufacturing field

Manufacturing field values were discussed in detail in Section 4.2.6, the notes here provide a basic background to the field's proposed setup. This field represents the direct labour value provided in the budget. The main objectives of these field inputs is to provide a link between the single-line shop labour value from the budget, with the decompressed schedule activities. A key consideration in achieving this has been to minimise the necessity for product and EVM system knowledge for the user while still maintaining a robust measuring outcome that can model the manufacturing process.

Considering dependencies between the TPB and schedule, and also looking at the difference between the time values of work effort vs. actual scheduled durations a method of allocation was derived that to date is delivering a workable outcome. From the initial trials it was found the method of applying milestone activities to the nine flexible 'Work Description Cells'

Autumn 2010 presented an opportunity to essentially repeat part of project T001. The EVM setup for this project (identified as T003) was similar to T001 but presentation of the worksheets and instructions for use had been improved since the 2009 trials. The approach taken for this project was to pass the data entry to the project engineer (PE) after some initial one-on-one training. Early effort and dialogue between the PE and researcher identified the modelled schedule slippage at the project's front end represented by the ES curve would be problematical if the tool is to be used for reporting externally. In short, the deviation between PV \& EV was not really reflecting the critical path which is the 'thing to watch' (Jacob \& Kane 2004) when making decisions about reporting project slippage with EV, particularly at this early stage of the project where the schedule's network is more parallel than serial (Vanhoucke \& Vandevoorde 2007). Reasons for this response were considered at the time as being either the influence of materials or skewed scheduling rather than poor progress as such (these matters are discussed more detail in Section 4.4.4). Through this trial there was also a suggestion to reduce the level of detail down further to perhaps just major milestones to help simplify its use. While overall the method received positive response in theory the realities of the required administration effort quickly eroded participation as workloads increased for the participant.

Balancing the need to allow the PE to focus on more pressing time-dependent manufacturing issues, the EVM data entry was taken-up by the researcher. At this stage user participation was not strongly pushed because system development was still immature and data streams although flowing still required management effort to ensure conformity and address system modification as required. It was also found that while the data entry of the PE was correct, commentary associated with EV allocation was not forthcoming, and this was an important 'data capture' exercise in this trial stage to understand allocation strategies and difficulties.

In parallel to T003 being setup and initially monitored, the forecasting calculations were refined into a form that allowed better interpretation than earlier efforts. As the project progressed and initial curve noise subsided, ES forecasting outputs were compared to the 'gut feel' forecasts of the PE which were made in isolation from ES forecasts. It was pleasing to see results from the last $50 \%$ of the duration of the project were showing correlation to the 'experience' based predictions. These results added confidence that the setup and application of the method was generating useful outcomes.

The final data sets reviewed in Chapter 5 cover a range of project examples which bring different aspects to the investigation and therefore curve responses can be considered with respect to these fundamental differences under the same project type. Table 4.4 summarises the projects reviewed in detail by this research. The project values have been rounded to the nearest thousand dollars, duration has been rounded up to the nearest week and labour hours are the actual values from the samples.

| Project Data Sets |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Reference | Value (AUD) |  | Duration (Weeks) |  | Labour Effort (Hours) |  |
| Project \# | Budget <br> (BAC) | Actual <br> Cost | Planned | Actual | Planned | Actual |
| T001 | $\$ 732,000$ | $\$ 656,000$ | 31 | 35 | 4730 | 4538 |
| T002 | $\$ 107,000$ | $\$ 95,000$ | 19 | 19 | 550 | 822 |
| T003 | $\$ 133,000$ | $\$ 136,000$ | 10 | 12 | 840 | 909 |
| T004 | $\$ 177,000$ | $\$ 186,000$ | 22 | 23 | 1055 | 1574 |
| T005 | $\$ 373,000$ | $\$ 392,000$ | 30 | 30 | 3500 | 4048 |
| S001 | $\$ 64,000$ | $\$ 66,000$ | 14 | 14 | 400 | 427 |
| S002 | $\$ 64,000$ | $\$ 62,000$ | 14 | 29 | 400 | 323 |
| S003 | $\$ 64,000$ | $\$ 66,000$ | 14 | 16 | 400 | 452 |
| S004 | $\$ 64,000$ | $\$ 73,000$ | 14 | 19 | 400 | 487 |
| S005 | $\$ 64,000$ | $\$ 73,000$ | 14 | 17 | 400 | 513 |
| S006 | $\$ 64,000$ | $\$ 73,000$ | 14 | 17 | 400 | 498 |
| S007 | $\$ 64,000$ | $\$ 73,000$ | 14 | 14 | 400 | 452 |
| S001-LO | $\$ 30,3000^{19}$ | $\$ 32,000$ | 14 | 14 | 400 | 427 |
| S002-LO | $\$ 30,300$ | $\$ 27,000$ | 14 | 29 | 400 | 323 |
| S003-LO | $\$ 30,300$ | $\$ 33,000$ | 14 | 16 | 400 | 452 |
| S004-LO | $\$ 30,300$ | $\$ 36,000$ | 14 | 19 | 400 | 487 |
| S005-LO | $\$ 30,300$ | $\$ 36,000$ | 14 | 17 | 400 | 513 |
| S006-LO | $\$ 30,300$ | $\$ 36,000$ | 14 | 17 | 400 | 498 |
| S007-LO | $\$ 30,300$ | $\$ 36,000$ | 14 | 14 | 400 | 452 |
|  |  |  |  |  |  |  |

Table 4.4 - Project Data Set Summary

The sample projects were discussed in Section 3.4.3 with respect to application development. Further expansion on their details is needed so as to outline the content of the project with

[^14]respect to each other for the reader. This is important when considering the outcomes discussed in the following chapters and modelling application for future work. A point that needs to be clarified here for future discussion is the relativity of project size within the context of this research. Small / short duration projects are considered to be those of less than $\$ 100 \mathrm{~K}$ value or less than 20 weeks duration. Reference to larger / long duration projects implies they are over this threshold.

The first five projects represent unique vessels however there are some similarities between some of the projects and hence why they were selected for inclusion in this study. A brief summary of each project is noted in the following dot points for reference by the reader and supplemented with some photos of each completed project in Appendix C to further clarify the equipment geometry.

- T001 - Large project; requiring LAP design and manufacture of a set of multiple identical vertical vessels (with legs) including internal supports, treatment of internal surfaces and external painting. Delivery of all vessels was a single shipment. EVM was used in parallel to running this project, but had little influence over the management decisions due to the methodology being in development only. The project received attention throughout its life cycle but experienced material delays that were on the critical path. This required rescheduling the project before manufacture commenced, the revised baseline was used for EVM analysis. The project had a late start due to other manufacturing activities, however the simple construction of the vessel enabled a recovery, posing questions about scheduling and EVM reporting.
- T002 - Small project; requiring LAP design and manufacture of a single vertical vessel (with skirt), including external painting and delivery to site. EVM was setup with input slightly lagging the projects execution.
- T003 - Small project; being a repeat of project T001, using the existing design and for a single vessel only under a very compressed time frame. EVM was run in parallel but in the back-ground to the project activities and decisions.
- T004 - Large project; requiring LAP design and manufacture of a single vertical vessel (legs), including platforms, ladders, external painting and delivery to site. EVM was setup and post processed, however the projects progress was monitored and recorded very closely as this vessel included ancillary equipment that was tied into the
vessel manufacture near the end of the build sequence. This project followed the typical manufacturing pattern observed in the years preceding the research where slippage was progressively incremental and then, near completion date, the projects labour effort would be increased significantly to recover by the delivery date.
- T005 - Large project; requiring manufacture (only) to the client's design for multiple identical vertical vessels (legs) including internal supports, piping, treatment of internal surfaces and external painting. EVM was again post processed and therefore did not influence decisions about managing the project. The project had a tight manufacturing schedule from the beginning, although labour effort was maintained the baseline was always considered too tight for normal workshop progress. Slippage continued throughout the manufacture, the project schedule was recovered by making alternative arrangements for the internal treatment activities which resulted in a significant recovery very late in the project.
- 'S' Series - Manufacture (only) using an existing LAP design, pairs of identical horizontal vessels (no legs), including external painting. These vessels were a repeat project.
- S001 - The project had an uninterrupted manufacture cycle and was delivered on time.
- S002 - The project had a long stop-work period due to more pressing project using resources therefore the project was in excess of $100 \%$ past the original planned duration.
- S003 - The project received consistent labour effort, but insufficient to maintain the schedule through the third quarter and as a result slipped, but due to the vessels simple construction slippage was partly recovered through a short increase in labour effort near the end of the planned duration.
- S004 - The project had a late start and a period of stop-work followed by consistent labour effort but at normal levels, therefore the project was delivered several reporting periods late.
- S005 - The project had a very late start followed by a high labour effort, finishing the project approximately $20 \%$ late.
- S006 - The project received consistent labour from early on but insufficient to maintain the schedule. The progressive slippage was not recoverable with the labour spike observed in other projects resulting in a $20 \%$ slippage.
- S007 - The project experienced a stop / start beginning, followed by a high labour period which recovered the delivery date.

In the above points there is reference made to legs or skirt with respect to the vessels orientation. As the name suggests this represents how the vessel is supported (Refer to Appendix C photos for clarity). This supporting geometry has significance for how serial or parallel a pressure vessel schedule can be developed. The relevance of this point was not realised till late in the research when recalling a short article by Vanhoucke and Vandevoorde (2009) in conjunction with Lipke (2012). The point was reinforced by a project experience through the course of 2012. The influence this geometry can have on scheduling and therefore EVM forecasting results is an important consideration, and therefore noted for future research that may be drawing on this work. Further elaboration on this subject is included in Section 4.4 .4 where it is more relevant.

### 4.4 Modelling Methods

All data sets were subject to a variety of EVM / ES and forecasting calculations, under three different frequency scenarios. In addition the ' S ' series were subject to processing using an alternative level of detail by eliminating materials from the project model, reducing the BAC \& PV to labour and sub-contracted services only. The following discussions address calculation details and aspects of this work taking into consideration project circumstances, organisational costing and the end products interaction with EVM related project modelling.

### 4.4.1 Measurement Period (Frequency)

The short projects investigated here have an overall project duration that is generally considered brief in project literature (typically measured in weeks) when discussing EVM application. The relationship between EVM and the project duration is an important consideration when deciding on the scale of application. When establishing the research scope and the spreadsheet for this project it was decided the measurement period needed to be modelled under varying scenarios so the effect of scale vs. duration could be better understood when making decisions about application. As described at the end of Section 4.2.7 the three frequency scales used for all projects reported in this research were: weekly, fortnightly and monthly. This band width provided a good fit for the projects investigated, while the weekly scenario suited the organisations weekly production focus.

The finer the measurement period the more sensitivity EVM has to any changes in the projects behaviour. The weekly cycle is more likely to report changes abruptly while longer periods have a tendency to illustrate trends rather than the responses seen in the weekly reports. These immediate or lagging characteristics can be useful or concerning depending on what is being sought from EVM reporting and the intended audience for the information being communicated.

### 4.4.2 Level of Detail (Granularity)

The level of detail is related to how closely project activities and the goods and services are represented by the EVM model. Modelling this application was in part established through the BAC material groups (4.2.2), the TPB engineering / QA fields (4.2.7) and most significantly the development of the Work Description Cell (4.2.6), addressing labour allocation details and their decompression / re-compression. This work is representative of the 'level of detail' characteristics as discussed in the practice standards and literature. These earlier discussions extensively explored the approaches used in setting up the processing of project data that became part of the TPB and hence the PV, EV \& AC curves from which all other performance and forecasting calculations are taken.

Another aspect of granularity is represented by the simplification of the data included in the projects EVM model. Earlier discussions pointed to modelling without materials. Using the ' S ' series data sets this option was explored by setting material values to zero to generate a series of labour only PV, EV and AC data which was then subject to the same weekly, fortnightly and monthly performance and forecasting analysis. Assuming this reduced 'level of detail' produced a robust outcome against the labour plus materials EVM outputs, the strategy would significantly improve uptake possibilities because of the reduction in administration effort to achieve the EVM measures.

### 4.4.3 Performance Measures and Forecasting

EVM calculations are carried out under the TPB data and its cumulative PV, EV \& AC values. Schedule analysis calculations were taken from the PMI Practice Standard for EVM First edition (2005) due to the work preceding the October 2011 Second Edition release. Earned Schedule formulas at the time of development were taken from the work of Likpe et al (2009) and Henderson (2004) for the most part.

Accompanying the full set of calculations shown in the TPB sample in Appendix B, are details of all formulas applied to the EVM data using standard EVM terminology and subscripts where they existed in the PMI standard or existing literature. The list of calculations present in this spread sheet is lengthy due to running the same calculation theory using slightly altered variants to influence performance factors or manipulating output for alternative presentation such as percentage or delivery date. To summarise the numerous calculations forming part of the TPB analysis the core formulas used, their source and comments on any variants are listed in Table 4.5 and Table 4.6 below, grouped into 'Variance / Index Measures' or 'Estimate at / to Completion Forecasting'. During assembly of this thesis formulas applied were cross checked with PMI's second edition standard and referenced to the 2011 edition unless differences were found in which case the 2005 standard or the relevant author is cited.

| Variance / Index - Core Performance Measures |  |  |  |
| :---: | :---: | :---: | :---: |
| Ref \# | Equation | Source | Comments |
| VI-1 | SV = EV - PV | 2011, p. 58 | \$ |
| VI-2 | $\mathrm{SV}_{\%}=\mathrm{SV} / \mathrm{PV}$ | 2011, p. 58 | \% of PV |
| VI-3 | $\mathrm{SV}_{\text {PMIt }}=\mathrm{PT}-\mathrm{AT}$ | 2005, p. 18 | Time-based measure |
| VI-4 | $\mathrm{SV}_{\text {PMIt\% }}=\mathrm{SV}_{\text {PMIt }} / \mathrm{AT}$ | N/A | Applied VI-2 theory |
| VI-5 | $\mathrm{SPI}=\mathrm{EV} / \mathrm{PV}$ | 2011, p. 59 | Ratio |
| VI-6 | $\mathrm{SPI}_{\text {PMII }}=\mathrm{PT} / \mathrm{AT}$ | 2005, p. 18 | Time-based measure |
| VI-7 | $C V=E V-A C$ | 2011, p. 59 | \$ |
| VI-8 | $\mathrm{CV}_{\%}=\mathrm{CV} / \mathrm{EV}$ | 2011, p. 59 | \% of EV |
| VI-9 | $\mathrm{CPI}=\mathrm{EV} / \mathrm{AC}$ | 2011, p. 59 | Ratio |
| VI-10 | $\mathrm{VAC}=\mathrm{BAC}-\mathrm{EAC}$ | 2011, p. 61 | \$ |
| VI-11 | $\mathrm{VAC}_{\%}=\mathrm{VAC} / \mathrm{BAC}$ | 2011, p. 62 | \% of BAC |


| Variance / Index - Core Performance Measures |  |  |  |
| :---: | :---: | :---: | :---: |
| Ref \# | Equation | Source | Comments |
| VI-12 | $\begin{gathered} \mathrm{ES}=\mathrm{C}+\mathrm{I} \\ \mathrm{I}=\left(\mathrm{EV}-\mathrm{PV}_{\mathrm{c}}\right) /\left(\mathrm{PV}_{\mathrm{c}+1}-\mathrm{PV}_{\mathrm{c}}\right) \end{gathered}$ | $\begin{aligned} & 2011, \text { p101 } \\ & \text { (Originally } \\ & \text { from Lipke } \\ & \text { et al 2009) } \end{aligned}$ | It is to be noted that the ' $I$ ' term presented in Lipke et al (2009) was split for calculations into: $\begin{aligned} & \mathrm{I}_{\mathrm{N}}=\mathrm{EV}_{\mathrm{AT}}-\mathrm{PV}_{\mathrm{c}} \\ & \mathrm{I}_{\mathrm{D}}=\mathrm{PV}_{\mathrm{c}+1}-\mathrm{PV}_{\mathrm{c}} \end{aligned}$ <br> This simplified the process of reviewing the EV (at AT) vs. PV at C when calculating $\mathrm{I}_{\mathrm{N}} \& \mathrm{I}_{\mathrm{D}}$ |
| VI-13 | $\mathrm{SV}_{\mathrm{t}}=\mathrm{ES}-\mathrm{AT}$ | $\text { 2011, p. } 100$ <br> (Lipke et al 2009) | Time |
| VI-14 | $\mathrm{SV}_{\mathrm{t} \%}=\mathrm{SV}_{\mathrm{t}} / \mathrm{AT}$ | N/A | Applied VI-2 theory |
| VI-15 | $\mathrm{SPI}_{\mathrm{t}}=\mathrm{ES} / \mathrm{AT}$ | $\text { 2011, p. } 100$ <br> (Lipke et al 2009) | Ratio |

Table 4.5 - Variance and Index Performance Measures

| Estimate at / to Completion - Core Forecasting Formulas |  |  |  |
| :---: | :---: | :---: | :---: |
| Ref \# | Equation | Source | Comments |
| EC-1 | $\mathrm{EAC}=\mathrm{BAC} / \mathrm{CPI}$ | 2011, p. 61 | \$ |
| EC-2 | $\mathrm{EAC}_{\mathrm{t}}=(\mathrm{BAC} / \mathrm{SPI}) /\left(\mathrm{BAC} / \mathrm{PD}_{\mathrm{R}}\right)$ | 2005, p. 17 | Time $\mathrm{PD}_{\mathrm{R}}=\mathrm{PD}$ Rounded |
| EC-3 | $\mathrm{EAC}_{\text {PMIt }}=\left(\mathrm{BAC} / \mathrm{SPI}_{\text {PMIt }}\right) /\left(\mathrm{BAC} / \mathrm{PD}_{\mathrm{R}}\right)$ | 2005, p. 17 | Applied EC-2 theory |
| EC-4 | $\mathrm{ETC}=(\mathrm{BAC}-\mathrm{EV}) / \mathrm{CPI}$ | 2011, p. 60 | \$ |
| EC-5 | $\mathrm{EAC}_{\mathrm{i}, \mathrm{j}, \mathrm{k}}=\mathrm{AC}+\frac{(\mathrm{BAC}-\mathrm{EV})}{\left[\frac{\left.\mathrm{EV}_{\mathrm{i}}+\mathrm{EV}_{\mathrm{j}}+\mathrm{EV}_{\mathrm{k}}\right)}{\left(\mathrm{AC}_{\mathrm{i}}+\mathrm{AC}_{\mathrm{k}}+\mathrm{AC}_{\mathrm{k}}\right)}\right]}$ | 2011, p. 62 | \$ <br> Also run using the 'i,j,k' quantities set to $2,4 \& 5$ running average. |
| $\begin{aligned} & \text { EC-6A } \\ & \text { EC-6B } \end{aligned}$ | $E A C_{C P I . S P I}=\mathrm{AC}+[(\mathrm{BAC}-\mathrm{EV}) /(\mathrm{CPI} \times \mathrm{SPI})]$ | 2011, p. 62 | \$ <br> Also run with $\mathrm{SPI}_{\text {PMIt }}$ (See VI-3) in place of SPI, run Ref \# EC-6B. <br> Represented on EAC plot by 'EAC ${ }_{\text {CPI.SPI- }}$ pmit' curve. |


| Estimate at / to Completion - Core Forecasting Formulas |  |  |  |
| :---: | :---: | :---: | :---: |
| Ref \# | Equation | Source | Comments |
| $\begin{aligned} & \text { EC-7A } \\ & \text { EC-7B } \end{aligned}$ | $\begin{gathered} \mathrm{EAC}_{\mathrm{CPI} . \text { SPIfv }}= \\ \mathrm{AC}+\left[(\mathrm{BAC}-\mathrm{EV}) /\left(\mathrm{CPI}_{\mathrm{f}} \times \mathrm{CPI}+\mathrm{SPI}_{\mathrm{f}} \mathrm{x}\right.\right. \\ \mathrm{SPI})] \end{gathered}$ | 2011, p. 62 | Factor applied to the CPI \& SPI terms. Several different weighting scenarios were run. Refer to plots and Appendix B for expansion. <br> Also run with $\mathrm{SPI}_{\text {PMIt }}$ (See VI-3) in place of SPI, run Ref \# EC-7B. <br> Represented on EAC plot by 'EAC ${ }_{\text {CPI.SPI- }}$ PMItfv' curve. |
| EC-8 | $\mathrm{IEAC}_{S V \mathrm{t}}=\mathrm{PD}_{\mathrm{R}}+\left(\mathrm{SV}_{\mathrm{t}} \mathrm{x}-1\right)$ | N/A | Simple approach set up to compare results with IEAC ${ }_{t}$ formula |
| EC-9 | $\mathrm{IEAC}_{\mathrm{t}}=\mathrm{PD}_{\mathrm{R}} / \mathrm{SPI}_{t}$ | 2011, p102 <br> (Originally from Henderson 2004) | Time |
| EC-10 | $I E A C_{\mathrm{t}, \mathrm{i}, \mathrm{j}, \mathrm{k}}=\mathrm{AT}+\frac{\left(\mathrm{PD}_{\mathrm{R}}-\mathrm{ES}\right)}{\left[\frac{\left(E S_{\mathrm{i}}+E S_{j}+E S_{\mathrm{k}}\right)}{\left(\mathrm{AT}_{\mathrm{i}}+\mathrm{AT}_{\mathrm{k}}+\mathrm{AT} T_{\mathrm{k}}\right)}\right]}$ | Concept of transferring EAC theory from Henderson 2004 | Applied EC-5 Theory, also run at different ' $\mathrm{i}, \mathrm{j}, \mathrm{k}$ ' quantities |
| EC-11 | $\mathrm{IEAC}_{t, \mathrm{IP}}=\mathrm{AT}+\left[\left(\mathrm{PD}_{\mathrm{R}}-\mathrm{ES}\right) /\left(\mathrm{CPI} \times \mathrm{SPI}_{\mathrm{t}}\right)\right]$ | Equation form with Performance factor from Henderson 2004 | IP = Index Product as performance factor |
| EC-12 | $\begin{gathered} \mathrm{IEAC}_{\mathrm{t}, \mathrm{IF}}=\mathrm{AT}+\underset{\mathrm{S}}{\left[\left(\mathrm{PD}_{\mathrm{R}}-\mathrm{ES}\right) /\left(\mathrm{CPI}_{\mathrm{f}} \times \mathrm{CPI}+\right.\right.}+ \\ \left.\left.\mathrm{SPI}_{\mathrm{f}} \times \mathrm{SPI}_{\mathrm{t}}\right)\right] \end{gathered}$ | Equation form with Performance factor from Henderson 2004 | $\mathrm{IF}=$ Index Factored as performance factor Used a factor $\mathrm{CPI}_{\mathrm{f}}$ or $\mathrm{SPI}_{\mathrm{f}}$ to alter their representation in the performance factor same theory as EC-7A |

Table 4.6 - Forecasting Formulas

### 4.4.4 Critical Path and Product Geometry

The relationship between EVM's performance measurements and a schedule's critical path has been discussed in several sections of this document notably in Section 2.2 .5 (p.31), where
it was evident there is agreement between authors that the EVM method does not have a strong connection with the schedule network and hence the critical path. This characteristic was noted in a practical context during trials associated with project T 003 (Section 3.4.3, p.78). At the time of this trial the outcome focussed consideration towards project scheduling, the overall plan and its relationship with the project's product and the 'small project' context of this study. Because of the small scope and relatively simple construction of the products in question it seemed there was potential to model these projects with a simple structure and bias to the critical path, and hence lessen the gap between EVM measures and the networks critical path. A project experience at the end of this research window, coupled with recent literature prepared by Lipke (2012) contributed to a deeper understanding of the theories behind "activity criticality" as out lined by Vanhoucke \& Vandevoorde (2008). The following paragraph discusses this project experience and its recognisable issues with respect to both EVM modelling for this project environment and its vulnerability due to its planintensive requirements.

During 2012 the host organisation undertook a significant project that had a tight schedule from the outset, which was developed using well established build methods. EVM was in the process of being adapted to the project, based on the planned build method for trialling in the back ground as done on previous trials. There were issues early in the manufacture cycle regarding obtaining 'critical' materials as planned. As a result it was necessary to review the products geometry (a large horizontal vessel with no legs) with respect to critical path thinking and modelling an alternative built strategy. The situation required a solution outside the 'normal build' approach to maintain progress. Through these forced circumstances it was found the product presented a more flexible build sequence than had been initially foreseen. This resulted in significant change to the project's plans. The manufacture moved away from its serial structure to one that included multiple manufacturing paths occurring in parallel for much of the duration. Following on from the resolution of this scheduling issue there was a significant change needed in the execution plan for a major sub-contracted work package element due to external factors related to risk management. The manufacturing matters resulted in a significant shift in schedule topology (Vanhoucke \& Vandevoorde 2009) and coupled with necessary managerial changes made relating to the high risk work package, the necessary re-planning completely derailed the hopes of running EVM live in the background of this project.

These experiences align closely with material presented by Williams (2003) in regard to dealing with the "rigidity required by the EVM model" (Section 2.3.1, p.41) and working from the basis of "having to make an unchangeable plan at the start of the project" ((Williams 2003) in Section 2.3.1, p.43), a contributing factor in the procrastination in setting up EVM for this project. These issues also re-ignited earlier thoughts, noted in the previous paragraph, relating to simpler scheduling aligned with critical activities as an alternative to methods shackled to the more traditional decomposition model provided simple product geometry permits such planning. If such planning could be effectively utilised on critical activities, or the more appropriately titled core activities, changes may not be as disruptive to the rigid EVM model.

Extending the idea of altering project planning to be more focussed on core activities is congruent with earlier discussions relating to engineering deliverables and their value (Section 4.1, p.87). Financially engineering activities are of low value relative to the projects in question when considering the BAC. However they hold a high value with respect to project progress and the critical path albeit for a short duration as their deliverable (the design) is a prerequisite to material procurement and hence the start date for manufacture. Simplifying the EVM model by eliminating material would be a benefit in promoting the methods uptake. However the lag between project start and commencement of manufacture would be problematical for the simplified method as there can be a significant "down time" (Lipke 2011a) period that would only accrue the low financial value of the engineering. Trial project T001 (Figure 5.2) illustrates this lengthy low value down time period that can occur between order placement and material delivery for these particular projects. This particular project was re-scheduled and EVM modelled against the new baseline. If the project had not been subject to material delivery issues that prompted the re-planning it is doubtful whether EVM would be capable of highlighting the significance of an early delay in engineering deliverables given such a small EVM planned value through a period of what can be considered 'down time' while materials are to be delivered. This question seems to have a connection between 'product geometry based scheduling' and a series of publications by Lipke discussing Earned Schedule and its application to: the critical path (2006), small projects (2011a) and schedule topology (2012). This subject is of obvious interest to further work and is briefly revisited in Section 6.4.

### 4.5 Chapter Summary

EVM needs three data streams to function: direct labour, direct project costs and fabrication progress with reference to time. At the outset LAP's record system did not provide all this data in readily transferable packages. Adjustments were made to channel direct labour and direct project costs into accessible formats. As to fabrication progress, this has been captured by a program of photographing progress (usually daily) and transferring the image files to a data base.

Application mechanisms developed for EVM centred on a Project Workbook customised for each project phase and numerical data streams. The tool provided a necessary 'standard' frame-work to support EVM's specific data needs but allowed adjustments in Project Budget to transfer to EVM detail (using its Excel format) to meld the characteristics of the business and the projects context so as to achieve the necessary flexibility in application. Coupled with the project schedule (and the Project Workbook inputs of booked hours and materials costs) a Time Phased Budget can then be developed in a simplified pro-forma which reflects the performance measurement baseline of typical projects.

Using this framework, twelve projects were identified for testing and data sets for each were prepared. (Seven of the projects were run twice - initially with materials costs included and then without materials costs).

While all of the projects are pressure vessels there are marked differences in scale among them and similarly there are important differences in vessel geometry. The latter is of particular importance. Vertical vessels need to be built in serial fashion while horizontal vessels can have work proceed in parallel - at least for some of the build sequence.

All data sets were subjected to the traditional 'S' curve display of PV, EV and AC, ES was represented on this same ' $S$ ' curve graph by overlaying its time base measure schedule variance $S V_{t}$ on a second axis. Time forecasting (IEAC ${ }_{t}$ ) scenarios were represented using $\mathrm{SV}_{\mathrm{t}}$ methodology, drawing on four established calculation methods and also applying a simple approach of adding $\mathrm{SV}_{\mathrm{t}}$ to the planned duration, completing the five base forecasting options. Of these time calculations, an additional eight variants of were applied to two of the formal methods to examine sensitivity to running averages and index weighting to CPI or SPI $_{\text {t }}$.

Cost forecasting (EAC) was represented through six established PMI based forecasting methods. In a similar fashion to time forecasting, two of the methods were extracted for further testing sensitivity of the running average using three alternative cases. The performance factor method, using the product of CPI / SPI ${ }_{\# \#}$, was then subject to an additional five calculation variants using a combination of different SPI $_{\#}$ indexes and weighting towards either the CPI or the $\mathrm{SPI}_{\#}$ index.

In relation to frequency variation, each project test was setup using weekly intervals (the frequency). Fortnightly and monthly frequencies were then calculated by rolling up the weekly data into the respective lower frequency trials. For each of the three frequencies the above ' S ', $\mathrm{IEAC}_{\mathrm{t}}$ and EAC calculations were repeated. This provided the research with a collection of project data for analysis represented by a total of 36 ' S ' curves, 156 ' $\mathrm{IEAC}_{\mathrm{t}}$ ' curves and 168 'EAC' curves in various configurations.

## CHAPTER 5

## 5 Analysis and Results

### 5.1 Preliminary Notes

In the preceding chapters the projects considered by this research have been discussed in the context of the broader EVM and project management community. Accordingly, the projects have been categorised as small or short duration projects. Specific project information was first introduced in Section 4.3, during presentation of their details. At that point the projects were further categorised with respect to one-another, recalling "Small / short duration projects are considered to be those of less than $\$ 100 \mathrm{~K}$ value or less than 20 weeks duration. Reference to larger / long duration projects implies they are over this threshold" (Section 4.3, p.110). Discussions in this chapter apply this definition unless noted otherwise.

There are some instances (near the start-up dates) where indexes such as SPI and CPI can produce unrealistic outcomes. This occurs when start-up is slow and material values are very high when formula divisors are near zero. This resulted in some of the forecasts formulas generating extreme values for one reporting period. Where this output was of a scale that completely obscured differences between non-affected or (lesser affected) forecasting curves, the cell in question was manually adjusted to rein in the peak so other data could be illustrated at a comprehensible scale. Because of this sporadic data intervention, each trial is provided with opportunity to flag where intervention occurred so values for that particular output can be disregarded at the relevant reporting period (data point).

Curve outputs generated by the project workbook and the TPB / EVM spread sheet available for each data set are as listed in Table 5.1. Each plot has been setup to output the time line in a percentage of the planned duration. This was done as EVM literature tends to talk in this scale when analysing forecasting performance etc and it allows comparisons to be made across the various curve outputs generated by this research in the wider EVM forecasting discussions. In addition each of the tabulated curves were produced for a: weekly, fortnightly and monthly frequency. Where curves display a blue horizontal dashed line it is reflective of the planned target for the labour and EVM curves, while a green dashed line is used as the
zero slippage reference for the $\mathrm{SV}_{\mathrm{t}}$ curve. The $\mathrm{IEAC}_{\mathrm{t}}$ forecasting curves use the blue dashed line to indicate the actual project outcome.

Specific curves included in the document for review with each data set are noted in the 'Outputs' field of the "Project Details, Setup \& Output Summary" table presented at the start of each trial's Review \& Analysis. However at a minimum each Project (T00... / S00...) includes the weekly frequency curves for: hours (CO-1), EVM \& SV ${ }_{t}(\mathrm{CO}-2)$, IEAC $_{\mathrm{t}}(\mathrm{CO}-3)$ and EAC (CO-6). This has been done to assist in visualising the reviewing comments as the outputs of this high sample rate curve provide the most detailed EVM response to project behaviour of the three frequency samples. Each of the eight weekly curves listed in Table 5.1 are included in the 'Review \& Analysis' for T001 only. Inclusion of one full set of curves for the weekly frequency provides opportunity to explore the back-ground data and outputs used during the research to make judgment about the EVM tool. It was also decided that it was not necessary (nor very practical) to include all seven 'S' series data sets and their Labour Only equivalents due to their repetition, therefore sets S 001 , S002 and S 006 only have been reviewed here. These three projects were selected as they represent varying project outcomes for the repeat project case.

The fortnightly and monthly curve outputs for all the ' $T$ ' and nominated ' S ' data sets are limited to the three curves (CO-2, CO-3 \& CO-6) for each frequency scenario. Both the fortnightly and monthly curves are provided in Appendix D and display sufficient detail to convey the methods response to the project's characteristics as a supplement to the weekly curves. The 'S' series Labour Only (LO) data sets for S001, S002 \& S006 are represented by the weekly curves only in the following sections, as the fortnightly and monthly cycle is sufficiently represented by the 'S' sets that do include materials.

In specifically analysing the curves as described above, there is opportunity to make connections between EVM literature, the project history and the industry partner's views on potential EVM benefits. Therefore only specific aspects of the trial curves are focused on as these smaller details contribute to the building up of knowledge of the methods capabilities and response. This practical application review phase helps take established EVM methods and theories into an industry application. From this perspective the review \& analysis contained in this section is purely based on behavioural aspects that have managerial benefits, be it project or business management. As a result the addressing of the research questions has
been dealt with using a qualitative approach relating to the application in question (small projects in pressure vessel manufacturing).

| Project Curves Generated for each Data Set ${ }^{\mathbf{2 0}}$ |  |  |
| :---: | :---: | :---: |
| Ref \# | Plot Title | Output Details |
| CO-1 | Project Hours for T... or S... | Displays the labour profile of the project (weekly frequency only) |
| CO-2 | EVM \& $\mathrm{SV}_{\mathrm{t}}$ Report Showing \% of Budget and Time | Plots PV, EV, AC \& $\mathrm{SV}_{\mathrm{t}}$ on the same plot. $\mathrm{SV}_{\mathrm{t}}$ (Table 4.5, Ref\# VI-13) |
| CO-3 | $\mathrm{IEAC}_{t}$ Forecast of Actual Duration $\left(\mathrm{AD}_{\mathrm{R}}\right)$ - Using Earned Schedule Methods | Plots EC-8 to EC-12 |
| CO-4 | IEAC $_{t}$ Forecast Stability as $\%$ of Actual Duration $\left(A D_{R}\right)$ - Varying i,j,k Factor \& Compared to IEAC SVVt | Plots EC-10 at four different $\mathrm{i}, \mathrm{j}, \mathrm{k}$ quantities and compares to EC-8 |
| CO-5 | IEAC ${ }_{t}$ Forecast Stability as $\%$ of Actual Duration $\left(\mathrm{AD}_{\mathrm{R}}\right)$ - Using a weighted 'IF' Factor on CPI / SPI ${ }_{\#}$ \& Compared to IEAC $_{\text {SVt }}$ | Plots EC-12 at CPI, balanced \& SPI ${ }_{t}$ weighting and compares to EC-8. Also plots EC-12 replacing $\mathrm{SPI}_{\mathrm{t}}$ with SPI \& $\mathrm{SPI}_{\text {PMIt }}$ weighted scenario for additional comparison to the above three weightings |
| CO-6 | EAC Forecast of Actual Project Cost (PC) - Using PMI Methods | Plots EC-1, EC-5, EC-6A / 6B, EC-7A / 7B |
| CO-7 | EAC Forecast Stability as \% of Actual Project Cost (PC) - Varying i,j,k Factor \& Compared to $\mathrm{SPI}_{\mathrm{t}}$ Weighted | Plots EC-5 at four different $\mathrm{i}, \mathrm{j}, \mathrm{k}$ quantities and compares to EC-7A replacing SPI with $\mathrm{SPI}_{\mathrm{t}}$ and weighted to this index |
| CO-8 | EAC Forecast Stability as \% of Actual Project Cost - Using weighted CPI \& $\mathrm{SPI}_{\#}$ Factor | Plots EC-7A at CPI, balanced \& SPI weighting. It also plots EC-7A replacing SPI with $\mathrm{SPI}_{\mathrm{t}}$ and weighting toward this index for additional comparison |

Table 5.1 - Performance and Forecasting Plot Formulas

### 5.2 General Observations

EVM as a complete method of project modelling proved adaptable to the projects that were subject to testing. The tool continued to output representative planned curves that reflected the various project aspects. A common theme among design and build projects was the noticeable front end 'down time' period while manufacturing waited for engineering and procurement to deliver major materials for fabrication. On the other hand 'build only' projects using readily available materials showed quick start-ups with a PV curve rising

[^15]sharply over a short period in response to rapid ordering and material receipt. Characteristics, such as these, were highly visible in weekly frequency samples but were progressively muted as the frequency rate reduced to fortnightly and monthly. Additionally the weekly TPB structure was an easier time period to work with as the host's production and project review activities are based on a weekly cycle.

In general, major materials (having a high percentage value of the BAC) were represented in the PV \& EV by sudden increases. The rapid change in the slope of these curves at material receipt is reflective of the effect major materials have on manufacture start-up (i.e. to start or not). This effect is emphasised by the $0 / 100$ allocation used for testing (Section 4.2.7, p.107) and it is debatable as to whether this allocation method and the effects it has on the PV / EV curves make the approach problematical to EVM reporting. In general as soon as material is received manufacture needs to commence as fabrication time-lines are typically compressed from the onset. Therefore steep PV curves on receipt of material will return a high deviation between the PV and EV if material is not received as planned or fabrication, representing the labour component of EV growth, does not commence shortly after material receipt. As an internal reporting tool for the PMO this feature could flag projects that have not commenced their fabrication. As a production control tool for major projects, EVM modelling in this way has potential to be a good "dashboard tool" (Vizzuett 2011) ${ }^{21}$, assuming the practicalities of embedding EVM in major project culture can be overcome.

Another observation in relation to trials generally is the reasonably consistent increase in PV value through the fabrication period. This stabilising period is observed between the steep rise from material deliveries and then a second rise caused by sub-contracted activities such as painting, which like material have a relatively high cost and short duration in comparison to the smoother direct labour costs accrued through fabrication.

A final general observation (before analysing results individually) is a reflection of the projects overall BAC and duration. It seems the two projects (T001 \& T005) which had relatively long duration and higher BAC (or more specifically higher planned labour values) displayed a greater proportion of consistent climbing of EV value. This was a reflection of

[^16]having a longer fabrication period where labour spikes were not able to produce the same impact on progress as they do in a short build period. To clarify, the labour spike for single vessel projects (serial build geometry) show similar peak hours, therefore if this same effort is applied to a project with a low overall labour content the impact on progress is high. However if the project has a high labour value overall, the spike's effect is lessened with respect to progress. This observation is an important consideration for the EVM application; firstly from a user perspective EVM had a better feel about its application on longer duration projects, as there is opportunity to see trends rather than responses to reactions. The second point is that slippage on longer duration projects cannot be fixed over a weekend and requires a more thoughtful approach and reactions need to start further out from the end date, while slippage on the short duration project is frequently fixed by this approach. Therefore a longer duration project requires a project management approach whereas the short duration projects can mostly be dealt with through production management to control the outcome.

With respect to Earned Schedule, the extension tool proved to be responsive to the project status throughout each trial, performing as literature suggests, providing a robust time measure of progress. While effort is required to get acquainted with its calculation method, once understood the process is simple to implement and becomes a valuable addition to the traditional EVM curve suite. For this project environment the inclusion of the ES curve on a second axis overlaying the PV, EV \& AC provides good visual information regarding slippage in a language that is clear to all parties and therefore could assist in making decisions about how far a project can slip before application of the classic late 'labour spike fix' which this project environment uses to correct slippage.

Specific behavioural observations and analysis are more appropriately made within the bounds of each trial, because each project has unique circumstances, scope and characteristics as noted in Section 4.3. This approach is also beneficial to the host organisation as it permits extraction of specific benefits relative to project types and how these can improve the management of such projects which can then be used for training and EVM knowledge transfer as the quest for uptake is continued. Each trial will be discussed in the following subsections, looking at each project individually, listing the projects fundamental information, EVM application and data adjustment details (Section 5.1), as some early applications preceded the automated distribution approach set out in Section 4.2. The analysis will then turn to the responses EVM generated (the 'S' and forecasting curves). Following
these individual trial reviews, the original research questions will be addressed qualitatively considering the value these outcomes have brought to the management of the projects in question and the processes generally used by the host organisation to deliver its projects.

### 5.3 Project T001 - Review and Analysis

### 5.3.1 T001 - Trial Details

Fundamental project details, EVM application, data adjustment details and outputs are summarised in the following table for reference to project outcomes.

| T001 - Project Details, Setup and Output Summary |  |
| :---: | :--- |
| Fundamentals | Comments |
| Characteristics | Long duration, high BAC value and labour hours. |
| Scope | Design vertical vessel with legs. Procurement of short and some long <br> lead-time materials, manufacture of multiple vessel, high value <br> subcontracting at the end of the project and delivery to site. |
| TPB Material <br> Distribution | All values manually entered. |
| TPB WDC Values | Labour Budget allocation for each WDC was calculated automatically. |
| TPB WDC <br> Distribution | WDC budget allocation was manually calculated and distributed across <br> the TPB. |
| TPB Actual Labour | Read by Excel from the 'Booked Hours" worksheet. |
| TPB Actual Material | Read by Excel from the 'Material Cost' worksheet. |
| EV Allocation | Materials - Read by Excel from the "Material Cost' worksheet. <br> Labour - Manually entered using the PV distribution from the TPB. |
| Data Intervention | Weekly - Nil <br> Fortnight - First data point for SPI <br> MonIt value set to 0.5 <br> Monthly - First data point for SPI PMIt value set to 0.5 |
| Outputs | Weekly - CO-1 to CO-8 (Sub-sections 5.3.2 to 5.3.4) <br> Fortnightly \& Monthly - CO-2, CO-3 \& CO-6 (Appendix D.1) |

Table 5.2 - T001 Project Detail, Setup and Output Summary

### 5.3.2 T001 - Labour, EVM and $\mathrm{SV}_{\mathrm{t}}$ Curves

The project had a long down-time period which was planned but forced the project to have a compressed schedule. This requirement was reflected in the 'Project Hours' plot $^{22}$ Figure 5.1 having a 14 week intense period on fabrication followed by some labour support through the sub-contracted period. The project finished 4 weeks late as sub-contractor work could not be compressed.


Figure 5.1 - T001 Weekly Project Hours (Ref CO-1)
The relationship between material receipt and the commencement of labour effort is illustrated by the sharp rise in weekly hours between $45 \%$ and $50 \%$. At this point the project received critical material for this particular vessel geometry; hence it had a serial schedule topology through this point.

As noted in the above labour discussion the project had a planned down-time period represented by the horizontal trajectory between $\sim 3 \%$ to $40 \%$ duration. The first area of interest in Figure 5.2 with respect to PV / EV deviation was between $45 \%$ and $55 \%$. As discussed above (Section 5.2, p.124) the slope of PV (due to planned material receipt) and EV (due to actual material and labour effort on delivery) illustrates how the curves are

[^17]affected by larger value items. It also shows how production information can flow from EVM depending on the modelling approach utilised. In this case if the additional labour value had not been added to the EV in the period between $50 \%$ and $55 \%$ the EV would have come down considerably with respect to the same PV point. $\mathrm{SV}_{\mathrm{t}}$ would have then shown a significant drop instead to the almost parallel output shown each side of the $50 \%$ mark.


Figure 5.2 - T001 Weekly EVM \& $\mathrm{SV}_{\mathrm{t}}$ Curves (Ref CO-2)

The second area of interest is between $80 \%$ and $90 \%$ complete where the $\mathrm{SV}_{\mathrm{t}}$ curve shows a sudden decrease in project slippage. This was caused by the delivery of high value parts for the vessels assembly on completion. The response is linked to earlier discussions regarding the idea of extracting critical schedule elements for the EVM model (Section 4.4.4). As these high-value components were not part of the vessels 'manufacture' their placement in the PV / EV model in questionable. If they were not included the slippage trend $\mathrm{SV}_{\mathrm{t}}$ was showing would not have been disrupted. This fluctuation also drew attention to the need to appreciate the effect of PV slope and EV deviation and how this translates to the $\mathrm{SV}_{\mathrm{t}}$ curve. The PV, EV data points just past $80 \%$ are very close to each other however the $\mathrm{SV}_{\mathrm{t}}$ curve is indicating a three week slippage. This large slippage is setup by the fact that the two preceding PV points are near horizontal (i.e. they have almost same value) so the EV has just fallen short of these
values delivering the $\mathrm{SV}_{\mathrm{t}}$ slippage. The next report point (just prior to $85 \%$ ) shows a sharp increase in the PV slope, while EV remains just under the previous PV values resulting in additional $\mathrm{SV}_{\mathrm{t}}$ slippage. If the materials in question had been received the week they were due (and not in the week after) the $\mathrm{SV}_{\mathrm{t}}$ would have returned to almost zero slippage for this steep PV / EV section. It is obvious in reality that a one week delay on the delivery of noncritical assembly material would not affect the project as indicated by the outputs. A lesson from this observation appears to be that as the curves approach their extreme horizontal and vertical limits the models behaviour becomes questionable. The fortnightly and monthly curves represent the project in a better manner, through softer curves. Based on this trial the lower frequency sample rate would generally be more suitable for reporting externally as the PV slope is less extreme, and although the disruption described above is still illustrated, its impact is less and for the monthly trial is lagging the actual event.

The two 'delivery of material' instances illustrated by this curve are supportive of the concept of modelling with a weighting towards critical elements only for these projects. It also outlines the earlier point that steep rises in the PV curve are of dubious benefit. From this trial it can be stated that if sharp PV rises are aligned with critical materials that affect fabrication commencement there is internal organisational benefit to have them present in the model. However if they are related to ancillary components, then their presence is not helpful to the reporting and in fact can become problematical for external reporting.

### 5.3.3 T001 - IEAC $\mathbf{t}_{\mathbf{t}}$ Forecasting

The $\mathrm{IEAC}_{\mathrm{t}}$ curve Figure 5.3 outputs five methods of forecasting using the equations: EC-8 to EC-12 as listed in Table 4-6. The IEAC $_{\mathrm{t}, \mathrm{IF}}$ (Ref EC-12) curve has been setup so it can be weighted toward the CPI or $\mathrm{SPI}_{\mathrm{t}}$ index, for this trial case it was best to weight the formula to $\mathrm{SPI}_{\mathrm{t}}$. Details of this scenario assessment are discussed below when reviewing Figure 5.5. The same approach was taken for all projects when deciding on the weighting balance to be applied.


Figure 5.3 - T001 Weekly IEAC $_{\mathrm{t}}$ Curves (Ref CO-3)

The simple and short equations of IEAC $_{\text {SVt }}$ and IEAC $_{t}$ (Ref EC-8, EC-9 respectively) performed well for this trial. They were not as influenced by CPI variation that became a common response for the early stages of the project. All curves show convergence at the final stages of the project and all forecasts were influenced by the disruption discussed in Section 5.3.2, illustrating the flow on effect poor modelling can have on the overall performance.

Further assessment was done for both IEAC $_{\text {\# }}$ and EAC using a similar strategy of firstly altering the running average applied to the $\mathrm{IEAC}_{\mathrm{t}, \mathrm{i}, \mathrm{j}, \mathrm{k}} / \mathrm{EAC}_{\mathrm{i}, \mathrm{j}, \mathrm{k}}$ and secondly adjusting the weighting applied to CPI or $\mathrm{SPI}_{\# \text {. As }}$. the methodology is the same for both IEAC \# and EAC discussion in "EAC Forecasting" (Section 5.3.4) is limited to the response of trial T001 only.

The next curve (Figure 5.4) applied to data assessment examines the $\mathrm{IEAC}_{\mathrm{t}, \mathrm{i}, \mathrm{j}, \mathrm{k}}$ curve by decreasing and increasing the ES / AT running average band width from two samples to five samples (i.e. ...i,j to g,h,i,j,k).


Figure 5.4 - T001 Weekly IEAC $_{\mathrm{t}, \mathrm{i}, \mathrm{j}, \mathrm{k}}$ Curves (Ref CO-4)

The result from this project (and typical of all other project trials) was not as anticipated. An assumption was made prior to setting up this test that increasing the band width would have a significant effect in reducing curve noise for this forecast method. The outcomes suggest there is very little overall benefit to be gained by adjusting this value. There was some separation noted around individual data point peaks as the band became wider, but these were not sufficient at the maximum width tested to be of value in removing curve noise. In a quest to seek out how far EVM and its features can be simplified the results of this test were compared against the simple forecast term IEAC svt (Ref EC-8). For this test there was not a lot of difference noted between the running average and simple form equation except at the start where the simple approach was more stable and more conservative between $50 \%$ and 80\%.

The final assessment curve used by the study took the IEAC $_{t, I F}$ term (Ref EC-12) and adjusted the weighting across three cases being:

- CPI favoured - CPI at $0.8 / \mathrm{SPI}_{\#}$ at 0.2
- Balanced case - CPI at $0.5 / \mathrm{SPI}_{\#}$ at 0.5
- $\mathrm{SPI}_{\#}$ favoured -CPI at $0.2 / \mathrm{SPI}_{\#}$ at 0.8

This test proved to be a useful refinement built into the research spread sheet, as there were cases where one or the other produced a better overall outcome across the two forecasting tools. For the most part it was reasonably clear whether favouring CPI or $\mathrm{SPI}_{\#}$ was the better option, however for the smaller (short duration) projects it was not as defined, as shown in Figure 5.5 where three distinct steps can be observed (excluding the upper green IEAC SvVt curve). In some cases it worked slightly better for the $\mathrm{EAC}_{\#}$ than the IEAC \# curve, where this $^{\text {c }}$ occurred the $\operatorname{IEAC} C_{\#}$ was favoured due the research's underlying time measuring theme. In a similar fashion to the previous review, the curves from this scenario were plotted against the simple IEAC $_{\text {sVt }}$ approach as a quick comparison of forecasting performance. Against these curves it is clear the IEAC Svt performs better.


Figure 5.5 - T001 Weekly IEAC $_{\mathrm{t}, \mathrm{IF}}$ (Ref CO-5)

### 5.3.4 T001 - EAC Forecasting

The EAC curve (Figure 5.6) outputs six methods of forecasting using the equations: EC-1, EC-5 to EC-7B as listed in Table 4-6. The EAC CPI.SPlfv and EAC $_{\text {CPI.SPI-PMItfv }}$ curves (Ref EC7A and B respectively) have been setup so they can be weighted toward the CPI or $\mathrm{SPI}_{\#}$ index, as noted in Section 5.3 .3 for this trial case $\mathrm{SPI}_{\#}$ weighting was the best setting. Details of this scenario assessment are discussed below when reviewing (Figure 5.8).


Figure 5.6 - T001 Weekly EAC Curves (Ref CO-6)

The response from this trial showed the equation $\mathrm{EAC}_{\text {CPI.SPIfv }}$ (Ref EC-7A) tracked close to the final cost throughout the project excluding the spike noted between $45 \%$ and $50 \%$ where a large quantity of material was received a week later than planned. In contrast to the IEAC\# forecast the effect of the non-critical material delivery received between $80 \%$ and $85 \%$ was not as noticeable in these results.

As done in the IEAC ${ }_{\#}$ review the next step in analysis was to extract the $\mathrm{EAC}_{\mathrm{i}, \mathrm{j}, \mathrm{k}}$ curve, vary the running average band width and compare it to an $\mathrm{SPI}_{\mathrm{t}}$ weighted equation that uses the EC-7A methodology but changes out the SPI for SPI $_{t}$. This equation did not include a
variable weighting function, just simply weighted to $\mathrm{SPI}_{\mathrm{t}}$. This was done to observe if the traditional SPI term can be abandoned so EVM can be introduced to the organisation with a minimal number of indexes to learn (i.e. $\mathrm{SV}_{\mathrm{t}}, \mathrm{SPI}_{\mathrm{t}}$ and $\mathrm{CV}, \mathrm{CPI}$ ).


Figure 5.7 - T001 Weekly EAC $_{\mathrm{i}, \mathrm{j}, \mathrm{k}}$ (Ref CO-7)

Varying the running average band width again did not produce a marked improvement although the maximum sample rate option did improve the curves response for the early part of the project. Output from this plot shows the running average method does not take effect until at least the full five sample points are available and this is perhaps why it does not improve the first few data points where the curves are typically most noisy. Observing the performance of the $\mathrm{SPI}_{t}$ weighted curve, for this trial it is clear the $\mathrm{SPI}_{t}$ has potential as an alternative to the SPI term.

Moving to the final assessment to check CPI / $\mathrm{SPI}_{\#}$ weightings the plot $\mathrm{CO}-8$ is presented, where all variants of the equation $\mathrm{EC}-7 \mathrm{~A},-7 \mathrm{~B}$ and $\mathrm{SPI}_{\mathrm{t}}$ can be compared.


Figure 5.8 - T001 Weekly EAC $\mathrm{Efw}_{\text {( }}$ (Ref CO-8)

In a similar fashion to the output of the $\mathrm{IEAC}_{t}$ weighting test, it is clear that the $\mathrm{SPI}_{\#}$ weighted equations provide the best outcome. It also provides confirmation the $\mathrm{SPI}_{\mathrm{t}}$ in the cost domain worked well for this trial.

### 5.4 Project T002 - Review and Analysis

### 5.4.1 T002 - Trial Details

Fundamental project details, EVM application, data adjustment details and outputs are summarised in the following table for reference to project outcomes.

| T002 - Project Details, Setup and Output Summary |  |
| :---: | :--- |
| Fundamentals | Comments |
| Characteristics | Short duration, moderate BAC value and labour hours. |
| Scope | Design vertical vessel with skirt support. Procurement short and some <br> medium lead time materials, manufacture one only vessel, low value <br> subcontracting at the end of the project and delivery to site. |
| TPB Material <br> Distribution | All values manually entered. |
| TPB WDC Values | Labour Budget allocation for each WDC was manually entered. |
| TPB WDC <br> Distribution | WDC budget allocation was manually calculated and distributed across <br> the TPB. |
| TPB Actual Labour | Read by Excel from the 'Booked Hours" worksheet. |
| TPB Actual Material | All values manually entered. |
| EV Allocation | Materials - All values manually entered. <br> Labour - All values manually entered. |
| Data Intervention | Weekly - Nil <br> Fortnight - Nil <br> Monthly - Nil |
| Outputs | Weekly - CO-1 to CO-3 \& CO-6 (Sub-sections 5.4.2 to 5.4.4) <br> Fortnightly \& Monthly - CO-2, CO-3 \& CO-6 (Appendix D.2) |

Table 5.3 - T002 Project Detail, Setup and Output Summary

### 5.4.2 T002 - Labour, EVM and $S V_{t}$ Curves

The project received some material early to accommodate a necessary change in critical material supply, so some value was added early that had not been planned. These changes altered the EV to PV path in the front half of the project. The changes were not re-scheduled as it was intended to see how EVM would respond. The project was completed on time due to the simple build and shorter than planned sub-contracted work at the end of the project.


Figure 5.9 - T002 Weekly Project Hours Curves (Ref CO-1)

The labour profile shows all the fabrication effort was in the second half of the projects duration. The booking of approximately 90 hours ( $10 \%$ of the total labour effort) the week before delivery indicates how the reduced sub-contractor planned duration provided opportunity to recover the project and how late it was running according to the plan.


Figure 5.10 - T002 Weekly EVM \& SV ${ }_{\mathrm{t}}$ Curves (Ref CO-2)

The first third of the $\mathrm{SV}_{\mathrm{t}}$ duration displays the effect the changes from the initial plan had on the outputs, initially ahead of schedule then progressively coming back to zero $\mathrm{SV}_{\mathrm{t}}$. The next third of the $\mathrm{SV}_{\mathrm{t}}$ curve varies as materials are received and the PV and EV moved through a series of steep rises. Fabrication effort started from $50 \%$ but the project was behind at this point and therefore modelled slippage continued as labour effort was unable to match the PV rise. The fortnightly curve dealt with the project's behaviour much better than the weekly or monthly curves. The front half of the fortnightly curve displayed an acceptable trend, while the second half showed consistent slippage till the last report. The recovery simply came down to an initial scheduling error allowing too much time for the sub-contracted works. This experience saw focus turn to schedule culture within the host's organisation and highlighted the advice of Fleming that EVM is only capable of reporting against a baseline (p.44).

### 5.4.3 T002-IEAC $\mathbf{t}_{\mathbf{t}}$ Forecasting

The combination of the changes in the plan, the late start to fabrication and skewed scheduling resulted in a poor forecasting outcome. Early predictions were optimistic and scattered, caused by the EV getting ahead of the PV (the change of plan), while the second half presented a pessimistic but more consolidated view finishing with an abrupt convergence to the planned completion in the last report period (an unrealistic plan).


Figure 5.11 - T002 Weekly IEAC $_{t}$ Curves (Ref CO-3)

The ancillary checks on the running average return minimal improvement of this curve while the weighting analysis indicated CPI was better but only in the back half of the project, perhaps a reflection of the more consolidated CPI curves (Figure 5.12). Given this project was an early trial the scattered results in the front half are probably attributable to incorrect application of the tool at this time coupled with the fact that the project experienced significant change. The lower frequency curves managed the changes better but still displayed varied results at the front and succumb to the skewed plan in the second half. Despite the erratic and unrealistic front end behaviour by all established methods the simple form IEAC svt provided a reasonably steady forecast throughout.

### 5.4.4 T002 - EAC Forecasting

All three frequency curves showed similar response in that the front half was varied but not scattered like the IEAC $\#_{\text {curves (i.e. the curves were moving in the same direction at each }}$ data point). The magnitudes of the deviations however were quite unrealistic (double or even treble the project cost).


Figure 5.12 - T002 Weekly EAC Curves (Ref CO-6)

The second half of the EAC curve was much more assured; all three frequencies showed significant settling from $50 \%$. The stability in this half was likely the reason for the weighted model to show better performance from a CPI favoured forecasting equation.

### 5.5 Project T003 - Review and Analysis

### 5.5.1 T003 - Trial Details

Fundamental project details, EVM application, data adjustment details and outputs are summarised in the following table for reference to project outcomes.

| T003 - Project Details, Setup and Output Summary |  |
| :---: | :--- |
| Fundamentals | Comments |
| Characteristics | Short duration, moderate BAC value and labour hours. |
| Scope | Manufacture only to LAP design one only vertical vessel with legs. <br> Procurement of accelerated material deliveries, high value subcontracting <br> at the end of the project (same vessel as T001 but for one unit only). |
| TPB Material <br> Distribution | All values manually entered. |
| TPB WDC Values | Labour Budget allocation for each WDC was manually entered. |
| TPB WDC <br> Distribution | WDC budget allocation was manually calculated and distributed across <br> the TPB. |
| TPB Actual Labour | Read by Excel from the 'Booked Hours' worksheet. |
| TPB Actual Material | All values manually entered. |
| EV Allocation | Materials - All values manually entered. <br> Labour - All values manually entered. |
| Data Intervention | Weekly - Nil <br> Fortnight - First data point for SPI ${ }_{\text {PMIt }}$ value set to 0.5 <br> Monthly - First data point for SPI <br> OMIt value set to 0.5 |
| Outputs | Weekly - CO-1 to CO-3 \& CO-6 (Sub-sections 5.5.2 to 5.5.4) <br> Fortnightly \& Monthly - CO-2, CO-3 \& CO-6 (Appendix D.3) |

Table 5.4 - T003 Project Detail, Setup and Output Summary

### 5.5.2 T003 - Labour, EVM and SV Curves

The project required a very short fabrication time, materials were received early allowing labour effort to start as planned. The compressed fabrication plan led to the EV lagging the PV for the projects duration, however the project followed the plan although finishing one week late.


Figure 5.13 - T003 Weekly Project Hours (Ref CO-1)

The PV and EV weekly curve only contained one steep rise early in the project, where major materials were received. The rest of the curve has a much smoother and consistent rise. This was achieved by altering the modelling approach used in trial T001, particularly in distributing the high value sub-contracting over several reporting periods for both PV and EV. While this increased the effort required to model and report it proved a more suitable approach for this very short duration project and offered a good outcome in understanding modelling effects of PV and EV .


Figure 5.14 - T003 Weekly EVM \& SV ${ }_{\mathrm{t}}$ Curves (Ref CO-2)

Prior to this project modelling of AC had not been considered, other than observing the responses produced by the spread sheets. This project produced a dip in the EAC curve (Figure 5.16) and warranted some thought. It was found that the sharp rise in the AC value was the underlying cause, as can be seen in the above curve there was a significant deviation between the EV and AC from $70 \%$ to $80 \%$ which correlates to the EAC dip. From this observation it was recognised that if cost forecasting was to be utilised then the AC modelling also required consideration as to how it might be best allocated. This project run raised some concerns about the reported early slippage, however as it turned out the forecast was quite good. The trial also showed that while additional effort can improve the outcome the administration effort at this level was not practical for the application. The very short duration of this project made the fortnightly and monthly (in particular) curves too simple, as a result there was very little that could be read into them except that the CPI proved a better weighted index.

### 5.5.3 T003-IEAC $\mathbf{t}_{\mathbf{t}}$ Forecasting

Although the curves appear quite scattered in this plot the scale needs to be considered when viewing them. For the most part the forecast remained within $+/-10 \%$ of the actual duration. The IEAC svt again performed very well in comparison to the traditional methods.


Figure 5.15 - T003 Weekly IEAC ${ }_{\mathrm{t}}$ Curves (Ref CO-3)

The rises in the forecast for the last two report periods is a reflection of the very flat PV and EV curves at this point. The relationship between curve orientation extremes and the method's sensitivity is an issue that needs consideration when setting up PV curves for these projects (as discussed in Section 5.3.2).

### 5.5.4 T003 - EAC Forecasting

Some separation between the curves is noted in the first half of the project, however the EV and AC tracked closely through this period in reality the deviation is small, with the exception of PMI's early version on SV time measurement which is a coarse measure at the beginning of a project's life.


Figure 5.16 - T003 Weekly EAC Curves (Ref CO-6)

The dip observed at the $80 \%$ mark is caused by the AC distribution approach taken in modelling the expense (Section 5.5.2). The downward trend from $40 \%$ is also attributable to the gradual separation of the AC from the EV until it abruptly returns to near EV levels at the $90 \%$ duration. In similar fashion to trial T002 all methods converged from approximately $50 \%$ duration. Over-all the $\mathrm{SPI}_{\mathrm{t}}$ associated method performed well adding support for the suggestion that the index could be a replacement to SPI for all aspects of EVM in this environment.

### 5.6 Project T004 - Review and Analysis

### 5.6.1 T004 - Trial Details

Fundamental project details, EVM application, data adjustment details and outputs are summarised in the following table for reference to project outcomes.

| T004 - Project Details, Setup and Output Summary |  |
| :---: | :--- |
| Fundamentals | Comments |
| Characteristics | Moderately long duration, BAC value and labour hours. |
| Scope | Design a vertical vessel with legs and platforms. Procurement of short and <br> some medium lead time material, medium value subcontracting at the end <br> of the project and delivery to site. |
| TPB Material <br> Distribution | All values manually entered. |
| TPB WDC Values | Labour Budget allocation for each WDC was calculated automatically. |
| TPB WDC <br> Distribution | WDC budget allocation was manually calculated and distributed across <br> the TPB. |
| TPB Actual Labour | Read by Excel from the 'Booked Hours' worksheet. |
| TPB Actual Material | All values manually entered. |
| EV Allocation | Materials - All values manually entered. <br> Labour - All values manually entered. |
| Data Intervention | Weekly - Nil <br> Fortnight - Nil <br> Monthly - Nil |
| Outputs | Weekly - CO-1 to CO-3 \& CO-6 (Sub-sections 5.6.2 to 5.6.4) <br> Fortnightly \& Monthly - CO-2, CO-3 \& CO-6 (Appendix D.4) |

Table 5.5 - T004 Project Detail, Setup and Output Summary

### 5.6.2 T004 - Labour, EVM and $\mathrm{SV}_{\mathrm{t}}$ Curves

This trial represents the most common type of project undertaken by the host organisation, where there is engineering effort required in both the vessel design and the structural attachments, fabrication is followed by an assembly and then sub-contractor works for surface treatment. The project's manufacturing process followed the plan, but was subject to significant slippage although most was recovered to finish one week late overall.


Figure 5.17 - T004 Weekly Project Hours (Ref CO-1)

The schedule recovery was achieved using the previously discussed labour spike strategy common to the host organisations production approach and by the quicker than expected subcontracted works at the end of the project. The labour spike impact was more effective on this project as it had ancillary equipment that needed to be built in addition to the vessel, providing a more parallel schedule up to the point of trial assembly, where both vessel and ancillary items are critical to further project progress. This scheduled pinch-point was planned between $70 \%$ and $80 \%$, but occurred between $80 \%$ and $90 \%$ which correlates with the second labour spike and the steep rise in the EV curve recovering most of the slippage by 95\% duration.


Figure 5.18 - T004 Weekly EVM \& SV ${ }_{\mathrm{t}}$ Curves (Ref CO-2)

The early 'ahead of schedule' $\mathrm{SV}_{\mathrm{t}}$ signal ( $20 \%$ to $30 \%$ ) was the result of major materials arriving one week early, but critical material for the vessels build arrived one week late (at the $35 \%$ duration point) the EV curve clearly displays these points and is reflected in $\mathrm{SV}_{\mathrm{t}}$. The project's moderately high labour effort and duration period ( $40 \%$ to $85 \%$ ) provided a suitable section of the schedule where EVM was able function well without material influencing curve slope. Through this period the $\mathrm{SV}_{\mathrm{t}}$ complemented the $\mathrm{PV} / \mathrm{EV}$ deviation observed. The lower frequency curves also illustrated the project actual outcomes, although the monthly curve tends to shift the peak $\mathrm{SV}_{\mathrm{t}}$ points and can overshoot where rapid recovery has occurred in a period. This behaviour is a function of the rolled up weekly costs used in this model. The fortnightly sample rate remains the better frequency if the tool is to be used for reporting externally.

This project established confidence in the method, if the project's late labour and subcontractor works were not 'crashed' the time forecasts and trends being indicated by $\mathrm{SV}_{\mathrm{t}}$ would have been accurate throughout. However recalling the point that forecasting is meant to be an early warning tool and $\mathrm{SV}_{\mathrm{t}}$ an indicator of status, it is fair to say the model worked well and responded quickly to the reaction that largely rescued the project schedule.

### 5.6.3 T004-IEAC $\mathbf{t}_{\mathbf{t}}$ Forecasting

Putting aside the fact that the project was 'crashed' and dramatically affected the time forecasting in the last four (weekly) reporting periods, the forecasts worked similarly in the more stable EVM environment between $40 \%$ to $85 \%$ duration. Again the simple IEACsvt curve showed good results, throughout compared to the other curves and particularly in the material influenced sections early on in the project.


Figure 5.19 - T004 Weekly IEAC $_{t}$ Curves (Ref CO-3)

As shown by the other trials adjusting the running average had little effect, the CPI / SPI ${ }_{\#}$ weighting for this project also had little impact. However the CPI did provide a slightly better result from the $40 \%$ duration point and was therefore setup as the favoured weighting index. The fortnightly frequency also produced the most useful curve for communicating status, the monthly periods are too long even for this length project and the curves do not have the informative 'feel' to them that the others display.

### 5.6.4 T004-EAC Forecasting

Curve stability was disrupted, more so for the SPI based curves, through the $20 \%$ to $30 \%$ early delivery of materials section. Following this, there was exceptional stability and forecasting from $40 \%$. For trials T002 to T004 there were good signs all EAC methods were
converging with each other from $40 \%$ to $50 \%$ duration, putting aside poor modelling strategies that momentarily dipped or peaked values with respect to the final costs, the curves were generally more stable than IEAC $\#$ methods.
The $\mathrm{SPI}_{\mathrm{t}}$ based curve was as good as any other method through the unsettling early period, but was slightly more conservative along the stable $40 \%$ to $85 \%$ periods, but not excessively different to the main cluster of curves.


Figure 5.20 - T004 Weekly EAC Curves (Ref CO-6)

### 5.7 Project T005 - Review and Analysis

### 5.7.1 T005 - Trial Details

Fundamental project details, EVM application, data adjustment details and outputs are summarised in the following table for reference to project outcomes.

| T005 - Project Details, Setup and Output Summary |  |
| :---: | :--- |
| Fundamentals | Comments |
| Characteristics | Long duration, high BAC value and labour hours. |
| Scope | Manufacture only of a multiple vertical vessel with legs. Procurement <br> short and some long lead time materials, high value subcontracting at the <br> end of the project and delivery to site. |
| TPB Material <br> Distribution | All values manually entered. |
| TPB WDC Values | Labour Budget allocation for each WDC was calculated automatically. |
| TPB WDC <br> Distribution | WDC budget allocation was manually calculated and distributed across <br> the TPB. |
| TPB Actual Labour | Read by Excel from the 'Booked Hours" worksheet. |
| TPB Actual Material | Read by Excel from the 'Material Cost' worksheet. |
| EV Allocation | Materials - Read by Excel from the "Material Cost' worksheet. <br> Labour - Manually entered using the PV distribution from the TPB. |
| Data Intervention | Weekly - Nil <br> Fortnight - Nil <br> Monthly - First data point for SPI PMIt value set to 0.5 |
| Outputs | Weekly - CO-1 to CO-3 \& CO-6 (Sub-sections 5.7.2 to 5.7.4). <br> Fortnightly \& Monthly - CO-2, CO-3 \& CO-6 (Appendix D.5). |

Table 5.6 - T005 Project Detail, Setup and Output Summary

### 5.7.2 T005 - Labour, EVM and $\mathrm{SV}_{\mathrm{t}}$ Curves

The project was very similar to T001, being the supply of multiple vessels, in addition it required the fabrication of ancillary internal equipment and an extra manufacturing step before painting. The design for this project was external so initial labour effort was applied to the ancillary component while procurement details were awaited. This delayed delivery of major vessel materials and compressed the fabrication time to an unrealistic point, but the schedule was used as prepared and provided a good testing ground for progressive fabrication slippage. Despite significant slippage by the later stages, recovery was achieved by 'crashing' major sub-contracting work by negotiating shift work with the supplier. The salvaging of the schedule is clearly visible in all time related curves shown here.


Figure 5.21 - T005 Weekly Project Hours (Ref CO-1)

Vessel fabrication commenced between $30 \%$ and $40 \%$ duration as reflected by the increased labour effort starting at this time. The major 'crashed' subcontracting began at $70 \%$ duration with all vessels at the contractors by $80 \%$ duration. From this point to completion was the work of contractors, supplemented with some labour ( $85 \%$ to $95 \%$ ) for internal assembly prior to delivery.


Figure 5.22 - T005 Weekly EVM \& SV ${ }_{\mathrm{t}}$ Curves (Ref CO-2)

Taking a boarder view of this project's ' $S$ ' curves the relationship between the slope of the $\mathrm{PV} / \mathrm{EV}$ curves and the reaction by $\mathrm{SV}_{\mathrm{t}}$ is again evident. Between $20 \%$ and $30 \%$ the PV initially has a very steep section, then returns to a more system stabilising slope. In the same period EV is almost horizontal resulting in a high $\mathrm{PV} / \mathrm{EV}$ deviation reflected by $\mathrm{SV}_{\mathrm{t}}$. Critical vessel fabrication materials were received between $30 \%$ and $35 \%$ this greatly diminished the PV / EV divergence and consequently inverted the $\mathrm{SV}_{\mathrm{t}}$ trend with equivalent magnitude. As discussed earlier although this response is noisy it does reflect the criticality of fabrication start-up and therefore useful for internal reporting.

In similar style to project T004 there was a long duration of high labour effort ( $35 \%$ to $80 \%$ ) where PV / EV slopes were reasonably consistent and the systems stability was reflected across all forecasting curves. The continual slippage of $\mathrm{SV}_{\mathrm{t}}$ was reflective of the too optimistic plan that had been put forward, so this result was convincing. Stability again became an issue as the sub-contracted work commenced and values were more 'lump sum' than the incremental labour values, resulting in EV's slope increasing as the crashed contractor delivered ( $80 \%$ to $90 \%$ ) and $\mathrm{SV}_{\mathrm{t}}$ responded accordingly. The fortnightly curve provides a smoother version of the weekly data, but not enough to lose the overall picture.

The monthly sample worked well on this longer duration project and is considered an acceptable duration for external reporting, but for internal reporting it is not responsive enough.

### 5.7.3 T005- IEAC $_{\mathrm{t}}$ Forecasting

As noted in T004 putting aside the fact that the project was crashed and this dramatically affected the final duration outcome, the forecasting was very good once the steep PV / EV slopes between $20 \%$ and $30 \%$ were past.


Figure 5.23 - T005 Weekly IEAC $_{\mathrm{t}}$ Curves (Ref CO-3)

The performance of the simple IEAC $_{\text {SVt }}$ curve was notably better on the project, it appears to have much better stability through the early stages of the project where most other methods have difficulty with the project start up. It seems the ES model and its interpolation between reporting points is more suitable than the traditional method where value allocation is 'lumpy'. The CPI index ( $\mathrm{IEAC}_{\mathrm{t}, \mathrm{IF}}$ ) weighting was better, although it peaked the forecast higher in the unstable zone it returned a more accurate forecast from $50 \%$ duration. All low frequency samples also returned positive curves attributed to the longer duration project.

### 5.7.4 T005-EAC Forecasting

As seen in the preceding curves, the EAC experienced an unsettled period while materials were planned and received ( $\mathrm{PV} / \mathrm{EV}$ slope approached its vertical and horizontal limits). However as seen in other trials the curves quickly converged and settled to within $10 \%$ of the project cost from $35 \%$ to $50 \%$ duration. It was again seen in the more detailed analysis of the $\mathrm{EAC}_{\mathrm{i}, \mathrm{j}, \mathrm{k}}$ and index weight review that the $\mathrm{SPI}_{\mathrm{t}}$ based forecast performed in a similar fashion to the $\mathrm{EAC}_{\mathrm{i}, \mathrm{j}, \mathrm{k}}$ curve shown here. As seen in the $\mathrm{IEAC}_{\mathrm{SVt}}$ curve the method is not as susceptible to the lumpy materials values common to these project.


Figure 5.24 - T005 Weekly EAC Curves (Ref CO-6)

### 5.8 Project S001 / Labour Only - Review and Analysis

### 5.8.1 S001 and LO - Trial Details

Fundamental project details, EVM application, data adjustment details and outputs are summarised in the following table for reference to project outcomes. The scope of this review includes 'Labour Only' (LO) trial data in the form of weekly outputs in comparison to the material loaded model under the relevant sub-headings below.

| S001 and Labour Only (LO) - Project Details, Setup and Output Summary |  |
| :---: | :--- |
| Fundamentals | Comments |
| Characteristics | Short duration, Low BAC value and labour hours. |
| Scope | Manufacture only to LAP design one horizontal vessel with no legs. <br> Procurement of short to medium lead time materials, low value <br> subcontracting at the end of the project. |
| TPB Material <br> Distribution | All values manually entered. |
| TPB WDC Values | Labour Budget allocation for each WDC was calculated automatically. |
| TPB WDC <br> Distribution | WDC budget allocation was automatically calculated and distributed <br> across the TPB. |
| TPB Actual Labour | Read by Excel from the 'Booked Hours" worksheet. |
| TPB Actual Material | Read by Excel from the 'Material Cost' worksheet. |
| EV Allocation | Materials - Read by Excel from the "Material Cost' worksheet. <br> Labour - Read by Excel from the "Labour for TPB" worksheet. |
| Data Intervention |  |
| (Full Set Only) | Weekly - Nil <br> Fortnight - Nil <br> Monthly - Nil |
| Outputs (Full Set) | Weekly - CO-1 to CO-3 \& CO-6 (Sub-sections 5.8.2 to 5.8.4) <br> Fortnightly \& Monthly - CO-2, CO-3 \& CO-6 (Appendix D.6) |
| Outputs (LO) | Weekly - CO-1 to CO-3 \& CO-6 (Sub-sections 5.8.2 to 5.8.4) <br> Fortnightly \& Monthly - N/A |

Table 5.7 - S001 / LO Project Detail, Setup and Output Summary

As this project and the following S 002 / S 006 trials are repeat projects the narrative describing the project plan is expanded in this S001 discussion. The commentary is then applicable to all S trials and can be referred to when considering the observational results of S002 \& S006.

### 5.8.2 S001 and LO - Labour, EVM and SV $_{t}$ Curves

This project was the first in a series of repetitive projects. The scope requires the manufacture of a simple horizontal vessel to an existing LAP design. Materials used are readily available apart for the spherical ends (a critical material) which had a planned delivery at approximately $42 \%$ into the duration. Main (shell) plates are the other critical and high value material (usually readily available) planned for delivery at approximately $22 \%$. There is low value (relative to the shell plate value) sub-contracted external surface treatment required at the end of the project.


Figure 5.25 - S001 Weekly Project Hours (Ref CO-1)

Labour commenced shortly after the project start date (illustrated above), preparing vessel attachments using short lead-time materials. Critical plate material was received late ( $\sim 35 \%$ duration, two reporting periods later than planned) and spherical ends were received as planned ( $\sim 42 \%$ duration). Labour was consistently applied from receipt of 'ends’ till delivery of the vessel to the contractors, with a higher labour (spike) effort from $55 \%$ to $70 \%$ duration. The project was completed on time. The zero labour near completion (last three reporting periods) represents what is usually additional labour needed to supplement contractor works in the final packing stage, however for these projects the client addresses this small labour scope with their own personnel.


Figure 5.26 - S001 Weekly EVM \& SV ${ }_{\mathrm{t}}$ Curve (Ref CO-2)

The high value plate materials are the main reason for the steep PV up to $\sim 22 \%$ duration (Figure 5.26), as this critical material was late and in a steep PV zone the $\mathrm{SV}_{\mathrm{t}}$ curve showed sharp project slippage until the plates were received at $\sim 35 \%$ duration. From here to the project's completion the ' S ' curves performed as theory suggests. The rise in $\mathrm{SV}_{\mathrm{t}}$ at $\sim 77 \%$ duration is simply a characteristic of the high sample rate which has the tendency to 'see' small PV / EV deviations particularly where the curves are approaching their horizontal limit, as in this zone. The project's duration is considered too short for the fortnightly and certainly for the monthly sample rate, although the fortnightly curve still provides enough detail to be of use for external reporting.

A trial using Labour Only (LO) and sub-contacted costs was carried out for this project (Figure 5.27), the expectation was the PV / EV curves would be represented by a more gradual increase towards the (reduced) BAC value. The resulting PV curve was for most part shaped as expected, producing a smoother profile than the material loaded curve. The early PV rise was a reflection of scheduled fabrication of associated non-critical components using short lead-time materials. With only modest labour effort, which did not complete the noncritical fabrication activities as scheduled, the EV curve was not able to rise to the PV profile.

As a result of the near horizontal EV the $\mathrm{SV}_{\mathrm{t}}$ responded sharply, indicating continual slippage to almost four weeks late at $\sim 42 \%$ duration. The reported slippage was nearly double that of the material loaded trial.


Figure 5.27 - S001 Weekly (LO) EVM \& SV ${ }_{\mathrm{t}}$ Curves (Ref CO-2)

The strong labour commitment from $42 \%$ to the $47 \%$ turning point quickly reined in the $\mathrm{SV}_{\mathrm{t}}$ indicated slippage. From $\sim 57 \%$ to $\sim 72 \%$ duration both the 'with and without material' trials were showing a similar curve profiles. The final $38 \%$ produced different profiles again. As noted at the minimum $\mathrm{SV}_{\mathrm{t}}$ turning point and again at the maximum turning point ( $\sim 77 \%$ duration) the $\mathrm{SV}_{\mathrm{t}}$ value approached a magnitude twice that of the material loaded trial.

It is believed the higher magnitude of the maxima turning points are due to the same labour value being used in both trials therefore calculated against a BAC that is approximately half the original value. The tail end of the 'Labour Only' curve shows a steeper rise than the material loaded profile this was caused by the inclusion of sub-contracted work. In a similar fashion to the 'labour value to BAC relationship', the net value of this sub-contracted scope is a constant across the two trials and therefore again a higher value in percentage terms to the
labour only BAC. As a result, these sub-contracted values are more significant to this labour only PV profile and reflected in a steeper rise in the curves as their value is added.

A preliminary conclusion to this EVM \& $\mathrm{SV}_{\mathrm{t}}$ observational review is that it can be said the exclusion of material generally improves the PV profile by smoothing the curve. However the labour value now holds a high stake in contributed value as it is added and therefore schedule variance value is magnified. But the relationship is not straight forward; vertical EV shift is an independent variable within the cost domain while $\mathrm{SV}_{\mathrm{t}}$ is a dependent variable referenced to the time domain.

### 5.8.3 S001 and LO - $\mathrm{IEAC}_{\mathbf{t}}$ Forecasting

The $\mathrm{IEAC}_{\mathrm{t}}$ forecast for the material loaded trial produced varying results between the forecasting methods. The difference in peak values was quite pronounced and stability was not really achieved until late in the duration ( $\sim 65 \%$ ). Again the simple $I E A C_{s v t}$ version of forecasting performed well, as it seems not as sensitive to PV / EV separation as the other methods, therefore deals better with the early project instability, that is now a recognised pattern in these projects'.


Figure 5.28 - S001 Weekly IEAC $_{\mathrm{t}}$ Curves (Ref CO-3)
When running the Labour Only trial instability in some calculations created problems for several of the methods. The resulting early forecast peak values were beyond reasonable graphical representation and were removed from the output plots in Figure 5.29.


Figure 5.29 - S001 (LO) $\mathrm{IEAC}_{\mathrm{t}}$ Curves (Ref CO-3)

An example of the problems encountered in the Labour only trial can be illustrated in the CPI derivation. In report number two (at $\sim 14 \%$ duration) the AC had acquired value due to labour commencing however the EV had not acquired any value as material received for the labour to commence were of zero value. The CPI then equated to a zero value (recalling CPI = EV / AC ) causing problems for the $\mathrm{IEAC}_{\mathrm{t}, \mathrm{IP}}$ and $\mathrm{IEAC}_{\mathrm{t}, \mathrm{IF}}$ forecasting methods as they included CPI in their equations denominator. Unlike the data intervention strategy applied to the 'full set' of calculations when addressing the isolated issues of PMI's early version of $\mathrm{SV}_{\mathrm{t}}$, this problem occurred in more than one time period and penetrated the calculations further as it was affecting CPI which was used extensively. For this reason, simply excluding the data sets rather than trying to intervene to salvage the erratic forecast outputs was considered the best approach.

As was found in the preceding curves the maximum and minimum values were more extreme in the Labour Only model, e.g. IEAC $_{\mathrm{i}, \mathrm{j}, \mathrm{k}}$ material model peaked at $\sim 170 \%$ at $35 \%$ duration while the labour only model peaked at $\sim 220 \%$ at $42 \%$ duration. Avoiding all these early project start-up issues the $\mathrm{IEAC}_{\text {svt }}$ again performed well in this simplified labour only project model, although its peak values also increased but in proportion to the smaller forecast value (from $115 \%$ at $35 \%$ duration to $125 \%$ at $42 \%$ duration).

### 5.8.4 S001 and LO - EAC Forecasting

The peak values for the two $\mathrm{SPI}_{\#}$ associated curves were unrealistic in this trial, from this curve (Figure 5.30) it is clear CPI favoured indexes were the best setting for the variable weighted indexes. The lower bound clustered curves peaking at $\sim 27 \%$ duration represent the CPI index weighed curves. The extreme $\mathrm{SPI}_{\#}$ index behaviour observed at this $\sim 27 \%$ duration also transfer to the $\mathrm{SPI}_{\mathrm{t}}$ weighted index plotted on the $\mathrm{EAC}_{\mathrm{i}, \mathrm{j}, \mathrm{k}}$ and the $\mathrm{EAC}_{\mathrm{fw}}$ plots (not shown for this project review, however refer to: Figure 5.7 (p.134) and Figure 5.8 (p.135) respectively for sample curves from project T001), however the SPI $_{t}$ peak ( $\sim 160 \%$ ) was not as extreme as the $\mathrm{EAC}_{\text {CPI.SPI }}(\sim 310 \%)$ and $\mathrm{EAC}_{\text {CPI.SPI-PMIt }}(230 \%)$ shown below.


Figure 5.30 - S001 Weekly EAC Curves (Ref CO-6)

Moving past the unstable period the curves quickly converged to show good cost forecasting again as in previous trials settling around the $50 \%$ to $60 \%$ duration.

The labour only model produced similar results to the material loaded EAC curves but again the magnitude of the maximum values were greater. The $\mathrm{EAC}_{\text {CPI.SPI }}$ curve was left out of this plot (Figure 5.31) due it its maximum value exceeding practical plotting limits. Despite the wildly over estimated final cost during the unsettled period the curves converged very quickly at $57 \%$ duration and remained very accurate to completion.


Figure 5.31 - S001 (LO) Weekly EAC Curves (Ref CO-6)

### 5.9 Project S002 / Labour Only - Review and Analysis

### 5.9.1 S002 and LO - Trial Details

Fundamental project details, EVM application, data adjustment details and outputs are summarised in the following table for reference to project outcomes. The scope of this review includes 'Labour Only' trial data in the form of weekly outputs in comparison to the full material model under the relevant sub-headings below.

| S002 and Labour Only (LO) - Project Details, Setup and Output Summary |  |
| :---: | :--- |
| Fundamentals | Comments |
| Characteristics | Short duration, Low BAC value and labour hours. |
| Scope | Manufacture only to LAP design one horizontal vessel with no legs. <br> Procurement of short to medium lead time materials, low value <br> subcontracting at the end of the project. |
| TPB Material <br> Distribution | All values manually entered. |
| TPB WDC Values | Labour Budget allocation for each WDC was calculated automatically. |
| TPB WDC <br> Distribution | WDC budget allocation was automatically calculated and distributed <br> across the TPB. |
| TPB Actual Labour | Read by Excel from the 'Booked Hours" worksheet. |
| TPB Actual Material | Read by Excel from the 'Material Cost' worksheet. |
| EV Allocation | Materials - Read by Excel from the "Material Cost' worksheet. <br> Labour - Read by Excel from the "Labour for TPB" worksheet. |
| Data Intervention | Weekly - Nil <br> Fortnight - Nil <br> (Full Set Only) |
| Monthly - Nil |  |

Table 5.8 - S002 / LO Project Detail, Setup and Output Summary

As this project is a repeat of S 001 comments are limited to the project's manufacturing history and the curve results.

### 5.9.2 S002 and LO - Labour, EVM and SV Curves $_{t}$

The project outcome was significantly delayed by production capacity. These particular projects are ordered rather than tendered, therefore receipt of orders is not known by the host
organisation. In this particular example workshop capacity was over-booked and the project was parked shortly after starting until higher priority work had been cleared and the project could be restarted.


Figure 5.32 - S002 Weekly Project Hours (Ref CO-1)

Labour commenced almost immediately (refer to above) in an attempt to complete the work in a small window of opportunity. Critical plate material was received early ( $\sim 15 \%$ duration, one reporting period earlier than planned) and spherical ends were received one week earlier than planned ( $\sim 35 \%$ duration). Labour was applied from week one when small items were received but the production window shut and work ceased at $50 \%$ of the planned duration. Fabrication re-started at $130 \%$ of the planned duration but remained inconsistent. The project was completed in 29 weeks, 15 weeks late.

Obviously 'Re-baselining' would have been the correct course of action however, as this was a trial completed post project, it was decided to leave the plan and observe the responses.


Figure 5.33 - S002 Weekly EVM \& SV ${ }_{\mathrm{t}}$ Curves (Ref CO-2)

The initial fluctuations in the $\mathrm{SV}_{\mathrm{t}}$ curve correspond with material deliveries; the continual linear slippage is reflective of the stop work phase. When labour was restarted $\mathrm{SV}_{\mathrm{t}}$ continued to show delays for several weeks and this seems a correct response. At re-commencement (at $130 \%$ of the planned duration) there was effectively $50 \%$ ( 7 weeks) of the original duration still to be completed, so the final slippage should continue to grow until labour effort had impacted the remaining scope enough to stop further slippage and stabilise the trend. It is noted the final $\mathrm{SV}_{\mathrm{t}}$ point finished correctly at 15 weeks late, as calculated by Actual Duration - Planned Duration (29-14 weeks = 15 weeks).

Due to the time scale of the delay the labour only PV curve (Figure 5.34) also had a steep vertical appearance, this was however a result of both PV curves compressed into half the horizontal time scale axis. Compared to the EV and AC curves this gave the appearance the PV was steep throughout. The material loaded curve did reach a higher BAC percentage value in the same time period before the stop work ( $\sim 42 \%$ of the $\mathrm{PD}_{\mathrm{R}}$ ). Observing the EV and AC for the material loaded trial was at around $65 \%$ of the BAC, while the labour only trial at stop work was at $\sim 30 \%$ of the BAC. For the labour only trial, this resulted in the majority of the project's value at completion being achieved in the re-started portion of the duration.


Figure 5.34 - S002 (LO) Weekly EVM \& SV ${ }_{\mathrm{t}}$ Curves (Ref CO-2)

### 5.9.3 S002 and LO - IEAC $\mathrm{t}_{\mathrm{t}}$ Forecasting



Figure 5.35 - S002 Weekly IEAC $_{\mathrm{t}}$ Curve (Ref CO-3)

Early material deliveries again destabilised all the forecasts except the IEAC SVt approach (as appears to be the typical IEAC \# front end behaviour). The stop work period was not really a forecast but a reported slippage, $\mathrm{IEAC}_{\text {sVt }}$ and CPI weighted $\mathrm{IEAC}_{\mathrm{t}, \mathrm{IF}}$ curves dealt with the stop work better, as there was little overshoot noted once work had recommenced.

The labour only model (Figure 5.36) showed greater instability in the first $50 \%$ where the project was being progressed continuing the trend of seeing higher peaks in this simpler model, noting IEAC $_{\text {SVt }}$ again was less affected through this zone. There was very little difference between the material and labour only curves from the stop work point, difference in peak values seemed to become less as the duration became longer allowing all time forecast methods to be retained in this Labour Only forecasting plot.


Figure 5.36 - S002 (LO) $\mathrm{IEAC}_{\mathrm{t}}$ Curve (Ref CO-3)

### 5.9.4 S002 and LO - EAC Forecasting

All curves had a very unstable response to early material deliveries (Figure 5.37), but showed settling by $40 \%$ just prior to the stop work period. The fortnightly frequency reduced curve separation although peaks were of similar magnitude. The monthly calculations were much better in this case, perhaps because the duration was longer (as in T001 \& T005 where monthly curves were also useful), and the curve had sufficient reporting periods to settle into a trend.


Figure 5.37 - S002 Weekly EAC Curve (Ref CO-6)

The PMI-SV ${ }_{t}$ method did not deal with the stop work scenario showing a similar response to that in the IEAC \# plots where the forecast effectively reported progress. The other curves remained sound through the stop work and once work re-started. CPI weighed indexes worked best as they did in the time forecast case. The $\mathrm{SPI}_{t}$ weighted index fell approximately half way between the PMI-SV ${ }_{\mathrm{t}}$ and the main curve cluster. (As noted in Section 5.8.4, this curve is plotted on the $\mathrm{EAC}_{\mathrm{i}, \mathrm{j}, \mathrm{k}}$ and the $\mathrm{EAC}_{\mathrm{fw}}$ curves, not shown for this project review, however refer to: Figure 5.7 (p.134) and Figure 5.8 (p.135) respectively for sample curves from project T001)

The labour only curve (Figure 5.38) followed the pattern of greater peak values, but settled by the same $40 \%$ duration. This model did affect the EAC $_{\text {CPI.SPI }}$ curve more than had been observed in the material loaded curve. It would seem CPI based (or weighted) methods are more stable particularity through a stop work phase. Drawing on project modelling literature it would seem logical to associate this observation with the fact that during stop work the time domain is significantly affected while the cost domain is not influenced when considering the project content only.


Figure 5.38 - S002 (LO) Weekly EAC Curve (Ref CO-6)

### 5.10 Project S006 / Labour Only - Review and Analysis

### 5.10.1 S006 and LO - Trial Details

Fundamental project details, EVM application, data adjustment details and outputs are summarised in the following table for reference to project outcomes. The scope of this review includes 'Labour Only' trial data in the form of weekly outputs in comparison to the full material model under the relevant sub-headings below.

| S006 and Labour Only (LO) - Project Details, Setup and Output Summary |  |
| :---: | :--- |
| Fundamentals | Comments |
| Characteristics | Short duration, Low BAC value and labour hours. |
| Scope | Manufacture only to LAP design one horizontal vessel with no legs. <br> Procurement of short to medium lead time materials, low value <br> subcontracting at the end of the project. |
| TPB Material <br> Distribution | All values manually entered. |
| TPB WDC Values | Labour Budget allocation for each WDC was calculated automatically. |
| TPB WDC <br> Distribution | WDC budget allocation was automatically calculated and distributed <br> across the TPB. |
| TPB Actual Labour | Read by Excel from the 'Booked Hours" worksheet. |
| TPB Actual Material | Read by Excel from the 'Material Cost' worksheet. |
| EV Allocation | Materials - Read by Excel from the "Material Cost' worksheet. <br> Labour - Read by Excel from the "Labour for TPB" worksheet. |
| Data Intervention |  |
| (Full Set Only) | Weekly - Nil <br> Fortnight - First data point for SPI <br> PMIt value set to 0.5 <br> Monthly - First data point for SPI PMIt value set to 0.5 |
| Outputs (Full Set) | Weekly - CO-1 to CO-3 \& CO-6 (Sub-sections 5.10.2 to 5.10.4) <br> Fortnightly \& Monthly - CO-2, CO-3 \& CO-6 (Appendix D.8) |
| Outputs (LO) | Weekly - CO-1 to CO-3 \& CO-6 (Sub-sections 5.10.2 to 5.10.4) <br> Fortnightly \& Monthly - N/A |

Table 5.9 - S006 / LO Project Detail, Setup and Output Summary

As this project is a repeat of the S 001 comments are limited to the project's manufacturing history and the curve results.

### 5.10.2 S006 and LO - Labour, EVM and SV t $_{t}$ Curves

The project tracked closely to plan through the material delivery phases, but drifted away during the fabrication.


Figure 5.39 - S006 Weekly Project Hours (Ref CO-1)

Labour started as planned (refer to above), stopped for only a week at $\sim 45 \%$ duration and then was maintained at a low level for the duration. Critical plate material was received as planned ( $\sim 22 \%$ duration) and spherical ends were received as planned ( $\sim 42 \%$ duration). The project was completed in 17 weeks, 3 weeks late.

Figure 5.40 - S006 Weekly EVM \& SV ${ }_{\mathrm{t}}$ Curves (Ref CO-2)

The flatter PV / EV curves section (around $20 \%$ to $35 \%$ duration as above) after material delivery where EV was lagging PV was reacted to sharply by the $\mathrm{SV}_{\mathrm{t}}$ as seen in other projects. Likewise when the ends were received and $\mathrm{PV} / \mathrm{EV}$ rose again and the $\mathrm{SV}_{\mathrm{t}}$ inverted its trend momentarily. Give that materials were received as planned the lower frequency curves produced a more realistic presentation of the event, (i.e. a slight fall to being with, resulting in a one week slippage at $42 \%$ duration). The remainder of the $\mathrm{SV}_{\mathrm{t}}$ curve behaved as expected.

The Labour Only model (Figure 5.41) produced more pronounced $\mathrm{SV}_{\mathrm{t}}$ slippage by the $42 \%$ duration, with a reported local minimum turning point in the downward trend of two and half weeks slippage vs. the material model at the same point reporting a local maximum turning point of a half a week slippage. When comparing the models it is the noted the plans become quite different in the early stages of the project, but following material receipt they then become similar.


Figure 5.41 - S006 (LO) Weekly EVM \& SV ${ }_{\mathrm{t}}$ Curves (Ref CO-2)

### 5.10.3 S006 and LO - IEAC ${ }_{t}$ Forecasting

It was expected this forecast (Figure 5.42) would have a good transition through the material delivery phase as critical items were received on time. Despite this outcome the curves still produced unstable results through the period $27 \%$ to $42 \%$ duration where PV / EV were approaching their horizontal limits.


Figure 5.42 - S006 Weekly IEAC ${ }_{\mathrm{t}}$ Curves (Ref CO-3)

At the commencement of the main fabrication period ( $42 \%$ duration) the curves had passed the unstable phase but oscillated throughout this project reflecting similarities in the labour profile. They also remained separated in their forecast, while $\mathrm{IEAC}_{\mathrm{SVt}}$ remained the most conservative throughout the project life.

As to the Labour Only results the forecasting (typically) was extreme through the unstable material to fabrication phase ( $27 \%$ to $42 \%$ duration), resulting in most curves being removed from the plot (Figure 5.43). The remaining three curves displayed high peaks as noted in other trials and IEAC $_{\text {Svt }}$ was again the most conservative.


Figure 5.43 - S006 (LO) Weekly IEAC ${ }_{\mathrm{t}}$ Curves (Ref CO-3)

### 5.10.4 S006 and LO - EAC Forecasting

This project incurred a high material AC resulting in an elevated overall project cost (Figure 5.44), all forecasts quickly stepped up to an anticipated high cost following material receipt. PMI-SVt was the stand out for extreme response, its continual sensitive behaviour is a reflection of its simple derivation ( $\mathrm{PT}-\mathrm{AT}$ ) with no capability to credit progress within the period unlike Lipke's $\mathrm{SV}_{\mathrm{t}}$.


Figure 5.44 - S006 Weekly EAC (Ref CO-6)

All other methods had similar responses to the data, although they fluctuated as did the $\mathrm{IEAC}_{\mathrm{t}}$ curves. Reviewing the lower frequency curves it is believed the EAC is best represented at a low frequency as the weekly sample rate can become noisy making it difficult to observe trends. From these lower frequency curves the forecast settled at $\sim 55 \%$ duration, similar to most other projects. The Labour Only model produced a similar overall profile, with the unstable front end settling by $\sim 55 \%$ (Figure 5.45).


Figure 5.45 - S006 (LO) Weekly EAC Curve (Ref CO-6)

### 5.11 Summary of Results

To grasp overall outcomes regarding important EVM capabilities for measuring and forecasting on these projects it is necessary to tabulate some of the observational results so patterns in responses and behaviours can be observed, relating to specific elements of interest. The main objectives from the trials were to:

- Observe $\mathrm{SV}_{\mathrm{t}}$ in the ' S ' curve environment, and note its capacity in providing a time status indication. As this was an observational activity with respect to each unique project, the analysis is focused on assessing the EVM outputs and their capacity to reflect the projects actual behaviour over its duration.
- To look for the stability point in forecasting methods and to assess what method performed best for that particular predictive situation and to note how accurate it was.

From the graphical outputs it does seem that, as literature and supporting research suggests Lipke's $\mathrm{SV}_{\mathrm{t}}$ is a robust measure across all project scenarios trialled here. Although a little more complicated to calculate, the capacity to accrue value within time periods helps the method achieve its status as a recommended method.

Table 5.10 in the following section provides a summary of the points of interest to this research and presents values of accuracy where applicable or simply notes the outcome for reference. Through review of curves it was noted the fortnightly frequency provided the best curves for observing settling and trends so these curves have been used to populate the following table unless noted otherwise. This was done because the weekly frequency was susceptible to noise while the monthly tended to lack sufficient data points to be able to provide a clear picture of the forecasting capacity within the short durations examined.

### 5.11.1 Tabulation of IEAC ${ }_{\#}$ and EAC Outcomes

To clarify the headings in Table 5.10 the following notes are provided:

- Methods Settling Point - Represents when in \% of Planned Duration $\left(\mathrm{PD}_{\mathrm{R}}\right)$ the main cluster ${ }^{23}$ of methods provided a consistent forecast with respect to each other.
- Best Performing Method - Nominates the most stable with a preceding (S), and the most accurate with (A) implying which method stabilised first nearer the final project outcome relevant to the forecast's domain. Equation references are taken from Table 4-5, p. 115 and Table 4-6, p.116.
- Index Weighting - Notes either CPI or SPI as the favoured index weighting based on assessment of both forecast domains.
- Stability Point - Records the \% of Planned Duration where the best (most accurate) method reached and remained with $\pm 10 \%$ of the final outcome.

| Summary of Results |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Reference | Methods Settling <br> Point | Best Performing <br> Method |  | Index <br> Weight | Stability point <br> $(\leq \mathbf{1 0 \%}$ achieved) |  |  |
| Project \# | IEAC | EAC $\#$ | IEAC $\#$ | EAC $\#$ | wrt <br> Both | IEAC $_{\#}$ | EAC $_{\#}$ |
| T001 | $55 \%$ | $80 \%$ | (S) EC-8 <br> (A) EC-9 | (S) EC-7A <br> (A) EC-7A | SPI $_{t}$ | $45 \%$ | $45 \%$ |
| T002 | $35 \%$ | $45 \%$ | (S) EC-8 <br> (A) EC-8 | (S) EC-7A <br> (A) EC-7A | SPI $_{t}$ | $30 \%$ | $60 \%$ |

[^18]| Summary of Results |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Reference | Methods Settling Point |  | Best Performing Method |  | Index <br> Weight | Stability point ( $\leq 10 \%$ achieved) |  |
| Project \# | IEAC ${ }_{\#}$ | EAC \# | IEAC\# | EAC ${ }_{\text {\# }}$ | $\underset{\text { Both }^{24}}{\text { wrt }}$ | IEAC\# | EAC ${ }_{\text {\# }}$ |
| T003 ${ }^{25}$ | 90\% | 45\% | (S) EC-8 <br> (A) EC-8 | (S) EC-7B <br> (A) EC-7B | CPI | From start | 90\% |
| T004 ${ }^{26}$ | 90\% | 45\% | (S) EC-8 <br> (A) EC-8 | (S) EC-5 <br> (A) EC-5 | CPI | 90\% | 45\% |
| $\mathrm{T} 005{ }^{27}$ | 40\% | 35\% | (S) EC-8 <br> (A) EC-8 | (S) EC-7B <br> (A) EC-1 | $\mathrm{SPI}_{\mathrm{t}}$ | 90\% | 50\% |
| S001 | 45\% | 45\% | (S) EC-8 <br> (A) EC-8 | (S) EC-5 <br> (A) EC-5 | CPI | 40\% | 50\% |
| $\mathrm{S} 002{ }^{28}$ | 45\% | 45\% | (S) EC-8 <br> (A) EC-8 | (S) EC-9 <br> (A) EC-9 | CPI | $140 \%{ }^{29}$ | 45\% |
| S003 | 30\% | 45\% | (S) EC-8 <br> (A) EC-8 | (S) EC-7A <br> (A) EC-5 | CPI | 95\% | From <br> Start |
| S004 | 130\% | 30\% | (S) EC-8 <br> (A) EC-8 | (S) EC-7A <br> (A) EC-7A | CPI | 70\% | 30\% |
| S005 | 70\% | 60\% | (S) EC-8 <br> (A) EC-8 | (S) EC-7A <br> (A) EC-7A | CPI | 30\% | 55\% |
| S006 | 110\% | 45\% | (S) EC-8 <br> (A) EC-12 | (S) EC-5 <br> (A) EC-5 | Balanced | 40\% | 30\% |
| S007 | 45\% | 45\% | (S) EC-8 <br> (A) EC-8 | (S) EC-5 <br> (A) EC-5 | CPI | 85\% | From <br> Start |
| S001-LO | 70\% | 60\% | (S) EC-8 <br> (A) EC-8 | (S) EC-1 <br> (A) EC-1 | CPI | 55\% | 70\% |
| S002-LO | 70\% | 45\% | (S) EC-8 <br> (A) EC-8 | (S) EC-5 <br> (A) EC-5 | CPI | 140\% | 140\% |
| S003-LO | 55\% | 30\% | (S) EC-8 <br> (A) EC-8 | (S) EC-1 <br> (A) EC-1 | CPI | From Start | 100\% |
| S004-LO | Did not | 80\% | (S) EC-8 <br> (A) EC-8 | (S) EC-1 <br> (A) EC-1 | CPI | 50\% | 130\% |
| S005-LO | 85\% | 70\% | (S) EC-8 <br> (A) EC-8 | (S) EC-5 <br> (A) EC-5 | CPI | 30\% | 110\% |

[^19]| Summary of Results |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Reference | Methods Settling Point |  | Best Performing Method |  | Index Weight | Stability point ( $\leq 10 \%$ achieved) |  |
| Project \# | IEAC\# | EAC\# | IEAC\# | EAC ${ }_{\text {\# }}$ | wrt <br> Both ${ }^{24}$ | IEAC\# | EAC \# |
| S006-LO | 55\% | 60\% | (S) EC-8 <br> (A) EC-10 | (S) EC-7A <br> (A) EC-7A | Balanced | 35\% | 110\% |
| S007-LO | 70\% | 45\% | (S) EC-8 <br> (A) EC-8 | (S) EC-1 <br> (A) EC-1 | CPI | 85\% | 80\% |

Table 5.10 - Summary of Result

### 5.11.2 Discussion

Time forecasting for the projects investigated was for the most part achieved best using the simple method of adding the $\mathrm{SV}_{\mathrm{t}}$ to the planned duration. Strictly speaking this is not really a forecast (as there is an assumption that whatever slippage has occurred will be added to the duration). While in theory this is possible if all the activities remaining are on the critical path and future performance follows the schedule (i.e. the CPM forecast strategy), in practice it is not necessarily the case. However it seems for this simplified IEAC $\#$ model and recognising the idiosyncratic behaviours of these projects, this generalisation is sufficient to achieve a usable result. Accuracy for time forecasting achieved useful outcomes at approximately $50 \%$ of the duration, however it is common to see curves with erratic results and in general the IEAC\# did not have the convergence and stability seen in the CPI curves after initial materials were received, typically from $40 \%$ to $50 \%$ of the planned duration.

In setting up EVM as a main-stream tool for pressure vessel fabrication projects, it would be wise to hedge both $\mathrm{IEAC}_{\#} \& E \operatorname{EAC}$ formulas against $\mathrm{SV}_{\mathrm{t}}$ due to its true representation of project status. But weighting any formula that uses the performance factor theory should be done to favour the CPI index. Because of the relatively short duration for most projects undertaken by the host firm, time forecasting is not really a necessity for in-house management of these projects, though its availability remains a value adding service to the client base. However more research needs to be done on the few, longer ( 20 to 40 weeks) to very much longer ( 40 weeks or more), duration projects the host organisation has undertaken. It is believed the time forecasting function would become internally beneficial in these longer projects where there is a large portion of direct labour and short duration production
strategies are unsuitable for time 'project' management requirements. In the longer duration projects examined here, EVM seems to achieve the documented reliability to support this view. Having assessed these projects and the forecasting outcomes, while simultaneously observing the financial aspects of manufacturing tighten (for this sector) over the course of this research, the EAC tool is potentially more important than the IEAC $_{t}$ tool to the host organisation at the conclusion of this research. Nevertheless, EAC was not the focal point for this research and therefore the suggested reversal of priorities is at this stage speculative only.

### 5.12 Assessment of Research Questions

Utilisation of research questions was proposed with two considerations in mind, promote focused outputs when preparing the research design and secondly to ensure specific application outcomes were consolidated when undertaking the observational analysis of the results. The content of these questions had a high association with issues and processes relative to the host organisation. Despite the narrow research sample (a single organisation) these problems are not isolated to this particular (host) organisation but common organisational challenges of similar industries. Therefore in setting the original questions, the source issues were generalised with the intention of making the EVM outcomes transferable to the broader fabrication sector.

### 5.12.1 Management-Orientated Activities

The research question proposed for the 'management-orientated activities' was $\mathbf{H}_{1(P M S)}$ "Establishment of an EVM based PMS decreases organisational related project management difficulties"

Throughout this research a project management system (PMS) suitable for the industry host (LAP) was formulated. The development was undertaken in parallel with EVM investigations and through this collaborative organisational / EVM based approach the system's structure was re-aligned to seek out the data needs of EVM, to ensure critical components for measurement were available in the system's function. EVM by nature has limited flexibility (Section 2.3.1, p.41) as to its data needs and a plan-intensive foundation, therefore the method requires rigid control over data stream input and availability. In contrast, literature recommends EVM systems have flexibility (Section 2.3.2, p.44). Resolving this paradox drove system development to clearly define functional boundaries, while providing opportunity for application flexibility within the functions themselves. This ensured data
requirements were met while not over-constraining the project management functions of the business.

The resulting PMS initially drew on existing organisational processes to become a central hub for the organisation's project activities. Through identifying surrounding business functions that contributed to the project life cycle, the centralisation concept matured into a project management office and project portfolio management (PPM) became a new business function for the organisation as a result of the research. The functional frame from which the PMO was created evolved the role of the PMO into one that has an 'organisation to project' focus and therefore became the central pool for the data streams. The centralised 'organisation to project' structure was able to then set the necessary system boundaries to provide the controls over the data streams, which are extracted from organisational functions. The data can then be utilised in the wider organisation, its programmes, portfolio and singular project management activities as required (at this point there is an element of flexibility available to users of the data).

The centralised control exercised by the PMO through the PMS structure, allows projects to be reviewed in a weekly cycle fitting with the existing operational management strategy. The integration of the; Operations (production activities) with Business needs (Accounts and Contracts) and Projects (client needs) has matured with research into a matrix management system that reviews 'operational and project' needs at the beginning of the week and 'project and business' needs at the end of the week.

The ongoing communication cycle binds both EVM data stream components such as; weekly booked hours, manufacturing progress, material ordering and receiving data with organisational activities such as; workshop deliveries and shipments, shop and project loadings, tendering and project invoicing. This cross discipline review process captures weekly project knowledge and status from individual projects and their managers, the information is then published across the whole business's operational domain.

The underlying PMS used by the PMO has its roots in EVM project data sourcing. Through this performance based connection with broader business management needs the PMO function has been able to extend itself into all aspects of the organisation. Reviews by the PMO achieve a level of information unity across the organisation and as a result there have
been significant improvements in the delivery of pressure equipment projects from an organisational perspective. It is therefore considered hypothesis $\mathbf{H}_{\mathbf{1}(\mathrm{PMS})}$ suggesting the 'establishment of an EVM based PMS decreases organisational related project management difficulties' is accepted by this observational research outcome.

### 5.12.2 EVM Method <br> EVM Research Question - $\mathrm{H}_{\text {l(EVM) }}$ Application \& Net Benefit

Recalling the principal EVM specific research question $\mathbf{H}_{\mathbf{1 ( E V M )}}$ ' $E V M$ can be applied to an SME, manufacturing heavy pressure equipment and in doing so deliver net benefits to its project management activities'. To clarify the objective of this hypothesis; it is intended to draw a conclusion based on the samples as to whether EVM; (part a) can be usefully applied on the projects sampled, and (part b) can deliver a 'net benefit' to the project management activities. The second part of this question can be considered in two aspects when responding as a result of the research outcomes. Initially, (part b-i) net benefit can be associated with the project management activities of the 'individual' project or the portfolio management activities of the 'projects'. The second 'net benefit' view point (part b-ii) can be taken from a wider organisational value perspective. Both of the (part b) elements are explored to determine whether the project management activities are enhanced sufficiently to exceed the additional effort of operating EVM concepts in this environment, i.e. to determine whether EVM presence delivers a 'net benefit' to project management activities.

## Application (Part a)

Through the application of EVM techniques to the five unique projects and the seven repeated projects discussed in Sections 5.3 to $5.10^{30}$ it is apparent even in a basic manual form EVM can be adapted to these pressure equipment projects and its behaviour is capable of representing a projects actual manufacturing history. However there are application and modelling difficulties that require conditions to be attached to $\mathbf{H}_{1(\mathbf{E V M})}$ (part a) 'EVM can be applied to an SME, manufacturing heavy pressure equipment...' when accepting the hypothesis. The conditional aspects are presented in the concluding response to this research question after addressing (part b) of $\mathbf{H}_{\text {(EVM) }}$

[^20]
## Net benefit - Singular Project / Portfolio of Projects (Part b-i)

During the discussions in Section 5.11.2 it was highlighted that the shorter a project's duration the less that management rigour was required as production strategies are usually capable of correcting project slippage using labour peaks at opportune moments in the product's build phase. As a result, management of time with the singular project is generally safely reduced to a production response guided by the project engineer's assessment of progress against the schedule's critical path. Therefore under these trial cases having EVM track projects is not of practical benefit to the outcome. However of the few long duration projects ( 20 week or more) examined there were indications EVM as a tracking option would supplement the schedule based critical path method and most likely be of value for the very long duration projects ( 40 weeks plus) but this will require further research to verify this expectation against the effort to maintain the tracking function.

The management of cost was however enhanced considerably by the presence of the EVM based project budget tool. The BAC has become a reference point for buying and decision making with respect to balancing supplier lead times with manufacturing options to meet scheduled plans. In addition to front end decision making, EVM data acquisition also improves visualisation of cumulative project costs, through a consolidated project finance report. Availability of this consolidated information assists in the activities of managing variations because of its weekly and activities-based structure, elements of changes in scope are easily identified and correlated through the data.

The availability of these cost management tools is a result of designing the PMS interface around receiving ongoing EVM data streams. An important outcome for assessing cost management benefits exits in the systems capability to deliver basic project finance data without the need to use EVM in a tracking mode. The structure means organisational day to day effort funnels cost data into projects, the assigned project engineer then has access to the upload information without the administrative effort required for full EVM tracking.

In similar vein to time management, the cost management benefit in forecasting has correlation to a project's scale with respect to the cost domain. Accordingly, on small projects its was found the information available through the EVM budget and reporting tools serviced most project's financial management needs adequately without the need for formal EVM forecasting. However it is still considered that very large projects would further benefit from
applying EVM to enable forecasting. Through this research it was observed cost overruns in these projects tend to occur in extended labour periods, correlating with the region of EVM forecasting where performance is better, that is after initial materials are received. To validate the latter cost performance ideas and their net benefit, further research on larger to very large projects will need to be undertaken.

## Application Conditions \& Net Benefit - Organisation (Part b-ii)

To conclude a response to the $\mathbf{H}_{\mathbf{1 ( E V M )}}$ acceptance conditions (part a) and to conclude on the net benefit discussion (part b) with respect the organisation and levels of application it is necessary to also consider the broader question of $\mathbf{H}_{1(\mathrm{EVM})}$ in this discussion, because of the interdependencies caused by levels of EVM application during the research. To supplement the academic response to this hypothesis it is also necessary to respond to the original research goals of the host organisation to provide practical outcomes for the industry context.

As explored in Section 5.12.1 above, application problems existed in the interface between EVM needs and the organisation as a whole. However for both specific questions and broader application challenges these issues are related to EVM methodology adaption and not principal EVM operators in data processing. Addressing these adaption issues required many iterations of application to achieve a system architecture that links project characteristics with business needs and organisational objectives. Each of these elements has specific roles to play in the triangular relationship of "organisational context, project management implementation and organisational strategy" as proposed by Aubry et al. (2012, p. 182). Using this model concept it is possible to align the levels of application difficulty with the current OPM3 framework consisting of: project, portfolio and programme management and the wider organisational context experienced in research and proposed by Aubry et al. The combining of these theories offers a response to the practical applications objective by mapping the host's (LAP) industry example with these higher level literature concepts.

To simplify the explanation of the relationship between OPM3, Aubry et al. (2012) and the practical issues of EVM application as experienced by the research, Table 5.11 presents the theory levels in a context relative to the host's organisational structure and then comments on the difficulties (conditions) of application for singular and portfolio management activities. It also outlines areas of net benefit that are achievable with EVM application where value is considered in the context of the whole organisational.

| $\mathrm{H}_{1(\mathrm{EVM})}$ - Conditions of Application Acceptance and Value |  |  |  |
| :---: | :---: | :---: | :---: |
| Source | Level | LAP Context | EVM Application - Difficulties and Benefits ${ }^{31}$ |
| OPM3 | Project | Singular Project | - Administration effort wrt users job function. <br> - EVM knowledge / Training needs of user. <br> - Defining EVM value at the technocrat level. |
| OPM3 | Project | Project Portfolio | - Project classification strategy. <br> - Project planning. <br> - Pre-commitment to product build sequence. <br> - Identifying portfolio conditions wrt operations. <br> - Project schedule wrt portfolio constraints. <br> - Modelling strategies and scheduling structure. <br> - EVM application intensity and simplification. |
| OPM3 | Programme | Business <br> Functions | - System configuration for EVM data feeds. <br> - Formatting EVM data for functional benefit. <br> - Cross discipline product knowledge wrt to project phases. <br> - Cross functional process knowledge wrt project phases. |
| Aubry et al. (2012) | Organisation | Systems | - Map EVM outputs to organisational benefits. <br> - Integrate EVM data with KPI measures. <br> - Simplify managerial theories and map to EVM outputs and identified benefits. <br> - Communicating EVM's connection with system strategies and product value for marketing. |

Table $5.11-\mathrm{H}_{1(\mathrm{EVM})}$ Conditions of Application Acceptance and Value

## Concluding Response to $H_{\text {l(EVM) }}$

Recalling the question in full 'EVM can be applied to an SME, manufacturing heavy pressure equipment and in doing so deliver net benefits to its project management activities'. Due to the different aspects of EVM delivering varying benefits a segmented response is used to summarise the overall answer to the question:

- Acceptance conditions of Part a "EVM can be applied to an SME, manufacturing heavy pressure equipment" - Accepted, but considering the following conditions:
- Administration effort requires a shift in the application away from the technical role of the project engineer (LAP's project manager) and moved up

[^21]to the portfolio level where data review and reporting have higher value to this function and can be pushed into the wider organisation for additional benefit.

- The use of tracking is not necessary on small projects as the raw data alone provides excellent support for the projects engineer in making informed decisions relating to the management of the individual project.
- Net Benefit of part b-i "EVM can be applied ... and in doing so deliver net benefits to its [singular \& portfolio] project management activities. - Rejection, is considered the overall response with respect to the small trials in the singular project context, while it is accepted at the portfolio level for larger to very large projects, based on the two larger project samples trialled. The reasons for this dual response are:
- At the singular level the project management structure of LAP is concerned with technical detail and decisions relating to project effort are based on both project needs and external factors relating to production. They are not necessarily schedule driven and therefore EVM measures will not add net benefit where EVM administration effort takes time away from live project engineering effort.
- Larger to very large projects are run using a network of effort coordinated between organisational functions. Therefore the ability to model the project and track with EVM promotes good project management practice, a strategy that is required when drawing on a team effort.
- Internal EVM reporting capabilities benefit the organisational commitment needed for large to very large projects. The visual communication tool helps to illustrate the status, delivery requirements and financial outcomes. Publication of this information promotes ownership and responsibility for the end product outcome.
- Regular external reporting improves client management, this limits surprises and therefore minimises opportunity for clients to influence production through reactive management based on their singular priorities, as is likely if they are not kept continually informed.
- Net Benefit of part b-ii "EVM can be applied ... and in doing so deliver net benefits to its [organisational] project management activities. - Acceptance, is considered the overall response with respect to having effective control of the project management process and capture of project data. The reasons are:
- Raw EVM project data provides opportunity to measure the business in a project capacity. This information is beneficial in assessing future commitment and analysing past experiences.
- EVM curve history can be used for development of standard product curves that flow into benefit for $\mathrm{H}_{4(\mathrm{EVM})}$.


## EVM Research Question - $\boldsymbol{H}_{2(E V M)}$

Recalling the proposition $\mathbf{H}_{\mathbf{2 ( E V M})}$ seeking confirmation 'EVM forecasts are accurate and reliable enough to be used in reporting manufacturing progress to clients and progress value to the fabricator' - Accepted, but considering the following conditions based on the observational reviews of trial projects:

- IEAC $_{t}$ curves are not of value on the short duration project, existing methods of CPM in conjunction with the schedule review sufficiently addresses the needs of these projects.
- Simply adding $\mathrm{SV}_{\mathrm{t}}$ to the planned duration provides adequate forecast for the sample projects tested. It is however recommended that additional tests be completed on long to very long duration samples when data is available to test the method over a longer direct labour cycle.
- EAC curves are highly unstable in the early part of the project but can be relied upon following material receipt and the commencement of the direct labour scope. The modelling of end-of-project high cost subcontracting also needs to be apportioned with care and the actual cost associated with these activities also needs to be accrued in a similar fashion to the planned value model.


## EVM Research Question - $\mathrm{H}_{3(E V M)}$ Reduced Project Model

The third hypotheses, was established as a continuation of the EVM related testing scope. Its purpose was to investigate if it was possible to reduce the labour and material EVM project model further as a means of reducing application effort. The question was stated as 'Excluding the cost of raw materials from the time-phase budget (TPB) does not significantly impact on indicator performance and simplifies user interaction'. - The proposal can be Accepted, based on the results of the seven projects trialled (S001 to S007) with and without materials (the reduced model is referenced as 'Labour Only' (LO) tests in results). However there are aspects of the outcomes that require noting, therefore the following comments are
provided to highlight areas where potential error can occur in the methods response or limitations in the testing scope.

Conditions of $\mathrm{H}_{3(\mathrm{EVM})}$ acceptance:

- All tests displayed a smooth more consistently increasing PV curve than the material loaded model, this typically resulted in an $\mathrm{SV}_{\mathrm{t}}$ curve that was more consistent in its project slippage representation.
- Early slippage was usually greater than that shown in the material loaded model and was noted as being more susceptible to late starting fabrication. Although this may well be reflective of the actual progress vs. schedule, the higher sensitivity could be an issue if reporting externally and time phasing was not synchronised with the 'late start' on all planned activities.
- The magnitude of the $\mathrm{SV}_{\mathrm{t}}$ in the LO model was usually more than that observed in the material loaded model. This was caused by the fact that the labour value holds a large portion of the BAC in the LO model and therefore slippage in labour effort is represented as a greater impact on project progress (or non-progress) by this model.
- The mid to later stages of the two models produce similar results, this suggests that once material deliveries have been passed the two model profiles tended to converge with each other.
- The method would be an advantage on long to very long durations only where direct labour is carried out over an extended part of the project's duration. This is an area of the research that requires additional testing with larger data sets and also more refined modelling scenarios within the existing data sets.
- Where the project has engineering design, the lengthy start-up period (such as that on T001) would require either critical materials or 'over valued' engineering deliverables to be included so there are measurable project activities in the first quarter of the project. Without this, the labour only model would not start reporting slippage till very late in the project cycle.
- 'Labour Only' forecast curves were also more sensitive than the material loaded model, generally the scale of early predictions were beyond representation as plotted data. Overall forecasting did not work as well on the simple model as on the material loaded model.


## EVM Research Question - $H_{4(E V M)}$ EVM Benefits beyond the Project

The final hypothesis, was setup to push EVM review past the immediate project to determine if the application of the method had use in other areas of the business that were concerned with front end project definition and assessment. The research question stated 'Having historical project data available in EVM format improves tender assessment, project risk \& contract management related functions for the organisation'. Through strong system and organisational maturity gains arising from EVM adaption over the course of the research, it was concluded this hypothesis can be accepted. An outline of the specific areas, as discussed at the beginning of this section under the review of $H_{1(\mathrm{PMS})}$ and $\mathrm{H}_{1(\mathrm{EVM})}$ explored the background aspects of the response to this question, the additional comments that follow are provided to more fully articulate the response:

- The continual collection of project data is effectively assembling a product specific library for the organisation. The areas of information EVM is enhancing relate to; commercial breakdown, fabrication effort, build history and manufacture techniques through the visual library records.
- It has been found the capturing of product and project information that conforms to the tight EVM data structure is teaching the organisation to retain clean data and is contributing to the organisations intellectual property that increases with the undertaking of each new project.
- The clean data records assist in identifying and handling contract variations.
- The knowledge transfer from past projects through access to 'lessons learnt' supported by product labour profiles, details of materials purchasing data, budget vs. actual expense, visual records (and potentially product ' $S$ ' curves in the future) are starting to be fed back into the organisations tender activities.
- The lesson learnt data base is influencing the tendering processes, through recognition of accountability as project data illustrates areas of tender shortcomings and duration realities.
- The project data is also being used at the PMO to build up product information stemming from the EVM based PMS such as weekly book hours across the portfolio and the portfolio profile load itself. When coupled with shop-load forecasting, these tools are helping to paint a clear picture of production capacity which can then be overlaid with proposed projects being sought by tender to assess project peak labour loads with respect to the portfolio loads and their forecast.


### 5.13 Chapter Summary

Numerous project curves were generated for each of the data sets examined using an array of EVM and ES performance based measures and forecasting equation combinations. Formulas were run with the data assembled into weekly packages which were then rolled up into lower frequencies and re-run to observe differences in behaviour attributable to frequency.

Time forecasting for the projects investigated was for the most part achieved best using the simple method of adding the $\mathrm{SV}_{\mathrm{t}}$ to the planned duration. Though not strictly a forecast (as there is an assumption that whatever slippage has occurred will be added to the duration), it seems for this simplified IEAC Svt model, this generalisation is sufficient to achieve a usable result.

Accuracy of time forecasting tended to settle at approximately $50 \%$ of the duration, however it was common to see curves with erratic results and in general the IEAC\# did not match the convergence and stability exhibited by the CPI curves once they had passed the point where initial materials had been received.

The research question established for the management-oriented activities proposed that 'establishment of an EVM based PMS decreases organisational related project management difficulties' $\left(\mathrm{H}_{1(\mathrm{PMS})}\right)$. Establishment of such a system proved extremely taxing and timeconsuming and ultimately led to establishment of a Project Management Office within the host organisation. As an issue quite separate from actually tracking projects using EVM, the PMS has resulted in significant improvements in the delivery of pressure equipment projects from an organisational perspective. Accordingly, the hypothesis $\mathrm{H}_{1(\mathrm{PMS})}$ is accepted.

In relation to the four hypotheses which were focussed on application of EVM methodology to projects at the host organisation, the results were mixed. The principal EVM specific research question $\mathrm{H}_{1(\mathrm{EVM})}$ was 'EVM can be applied to an SME, manufacturing heavy pressure equipment and in doing so deliver net benefits to its project management activities'. For the purposes of analysis, this question had to be separated into its component parts. It was accepted (conditionally) that EVM can be applied to an SME, manufacturing heavy pressure equipment but as to delivering net benefits the context is critical. For short duration projects there is little to be gained from EVM and the effort involved in its application is unlikely to be rewarded. For large projects (more than 20 weeks duration) there may be net benefits in

EVM tracking, particularly where the client has sought an objective reporting process. However it is still considered that very large projects (more than 40 weeks) would further benefit from applying EVM to enable forecasting particularly in relation to control of costs. To validate the prospective cost performance benefit, further research on larger to very large projects would be needed. At the level of the organisation as an entity (rather than the specific project level) it is accepted that there are net benefits so that acceptance of the hypothesis is considered the overall response with respect to having effective control of the project management process and capture of project data. The specific reasons are:

- Raw EVM project data provides opportunity to measure the business in a project capacity. This information is beneficial in assessing future commitment and analysing past experiences.
- EVM curve history can be used for development of standard product curves that flow into benefit for $\mathrm{H}_{4(\mathrm{EVM})}$.

Application of EVM methodology, in order to realise the organisation-level benefits, can of course take place retrospectively, rather than having to be run 'live'. This advantage considerably eases the administrative difficulties implicit in the exercise.

Of the remaining three EVM hypotheses, the second proposition $\mathrm{H}_{2(\mathrm{EVM})}$ 'EVM forecasts are accurate and reliable enough to be used in reporting manufacturing progress to clients and progress value to the fabricator' was accepted conditionally (i.e. it is most applicable to projects of longer duration, and after major materials have been received).

In relation to $\mathrm{H}_{3(\mathrm{EVM})}$ 'Excluding the cost of raw materials from the time-phase budget (TPB) does not significantly impact on indicator performance and simplifies user interaction' the hypothesis was accepted, though with some conditions. Essentially, the exclusion of materials does further simplify use of EVM processes and helps smooth PV curves. However indicator performance can become exaggerated or otherwise compromised to some extent in specific situations, as when fabrication is late in starting.

The final hypothesis $\left(\mathrm{H}_{4(\mathrm{EVM})}\right)$ proposed that 'Having historical project data available in EVM format improves tender assessment, project risk \& contract management related functions for
the organisation'. Based on the strong system and organisational maturity gains arising from EVM adaption over the course of the research, this hypothesis was accepted.

## CHAPTER 6

## 6 Conclusion

### 6.1 EVM Application

The representation of EVM in a broad brush educational setting, can present the tool as one that requires planning via a schedule (time domain) and budget (cost domain), it then combines the two elements so that a measure of progress can be achieved. This simplification is conceptually correct and the two domains represent the spectrum of the method. However the method is not capable of functioning without a sound PMS to support the data necessary to feed the tools appetite for information. Furthermore, this research has illustrated that without a very sophisticated understanding of project modelling (schedule structure and cost allocation) the outputs will be potentially troublesome to the project in some degree, depending on the modelling inadequacies and whereabouts in the outputs the results become skewed. The impact of this is amplified when the user is unaware of fundamental EVM workings, in which case results take on a meaningless form due to the disconnection between the projects schedule and EVM's model of the plan and the progress being made by the project.

Commencing application on the single project is an essential starting point for developing an understanding of the tools details and its needs. Small and simple incremental steps are a recommended strategy for application development. The building up process that comes from this simple start encourages appreciation of the connection between the domains, data needs and the form of its delivery. Grasping the relationship between these low level details and their delivery requirements forms the underlying principles in shaping the PMS, which in turn becomes the foundation for the methods organisational uptake. It needs to be clear in this application discussion that there is a vast difference between achieving EVM organisational integration (addressing the complicated issue of resolving method details) and EVM organisational acceptance (addressing the complex issues of resolving user uptake).

For the small business application as studied by this research, it may seem a logical approach to seek solutions using commercial software; however caution would need to be exercised in this approach as a first step. With many off-the-shelf solutions, there is a risk that the product
will not fit the problem and acceptance falls by the wayside as the processes of application are not tailored to the business activities, which have a natural tendency to converge to the most efficient solution that delivers the required result. With EVM in particular there is a high dependency on finding organisational solutions that fit the methods workings relative to the target application. This is driven by the need to have strict data feed requirements but to also have user flexibility so processes of project management are not over constrained. Against this background, a shift to commercial software adaption is not a recommended approach unless and until the integration stage of the application is resolved from first principles through trial and error.

Once all application and integration problems are resolved, effort should then be turned to refining user issues that can make the method part of the organisations main stream process. It is at this point that commercial software solutions could be applied as they would likely offer a singular platform solution to the time and cost domain effort. Having a sound structure and crisp interface behind EVM's objectives and workings enables clear guidelines, benefits and training to be presented. Delivery of these essential elements with efficiency and meaningful alignment with practical application are necessary in addressing the complexities of meshing the randomness of the human elements in managing projects with the planning intensive and relatively inflexibility of EVM methodology.

Based on the research experiences, the above paragraphs describe the broader application processes of EVM from inception through to the acceptance phase. Within these research experiences there are aspects of specific application that expand on the previous points but relative to the host organisation and the project environment studied.

There is literature support for EVM application on all projects and encouragement to experiment with EVM in more simple forms than those evolved as a result of meeting the needs of the US defence sector. Fleming and Koppelman conclude on this view, recommending a return to the "original approach used by the industrial engineers" (2010, p. 34) in factories of the 1900 's, but draw on critical elements that have emerged over the years of refinement. For this research, this advice is fitting and encouraging given the application studied is a 'factory floor' environment. The combination of limited human resources, noninnovative end product and a hybrid portfolio / production project environment poses challenges for traditional application theory and its singular project beneficial outputs.

Responding to these constraints required solutions to be adaptable to the challenges of the host environment. Breaking down the elements of EVM, as described in the opening paragraphs, provides opportunity to explore the 'critical elements' and commence aligning the project environment with EVM's underlying structure. From this it is found the basics are essential foundations to building an EVM system and therefore offer little opportunity to simplify. However as the adaption phase moved away from the principal structure, flexibility and simplification strategies become more tangible. At this point there is also closer alignment with more general project management and business practices.

Early research effort saw opportunity to provide simplification in the budget process, and through continual refinement the allocation methods became equally simplified to the point that the tool is an embedded part of the PMS. Schedule structure was not realised till much later in the research program, but its association with existing practices and practical application make this refinement a powerful vehicle to achieve simplification objectives. Scheduling in stripped down form, better alignment to the critical path and applying considerations to the early, late or planned scheduled dates (Fleming \& Koppelman 2010, pp. 73-4) provides opportunity to combine accepted project management activities with strategies that simplify the EVM modelling component that will deliver more adaptable EVM outcomes.

Research outcomes illustrated that the level of application associated with EVM organisational integration offers significant opportunities to simplify EVM and to shape its benefits so they form part of the operational processes of the organisation. A key objective of this application phase is to build in essential system flexibility, by designing its backend to plug into raw data streams and mould the front end to suit the organisational culture, its established processes and to manipulate the project management culture so strategic objectives of full EVM capabilities become part of the PMS. The development of the project budget was an example of this 'research learned' integration phase. Using the raw data from the estimate worksheets and creating a front end user interface that worked for project procurement and engineering (internal customers of this tool), the development was able to simplify estimate details and the allocated costs to suit EVM when taking the data across to the TPB.

The final stage of application, being organisational acceptance can again be illustrated through lessons from this research. This higher level of EVM application seeks to communicate the method's objectives and benefits in a way that acknowledges practical limitations of application between EVM and the organisation, but continues the work of the integration effort by complementing it with strategic delivery of EVM outputs catalyse the culture towards better project management methods. EVM reporting is a tool that has high value at this application level due to its visual impact, so while simply rolling out curves is eye catching to the novice, the realities of EVM effort erode enthusiasm (as experienced). However it was found by exploring the value added by such outputs, and presenting this in a context relative to the areas of values there was better support for pursuing the strategies by users. An example of direct value from this research was identifying that LAP did not necessarily require EVM curves to manage time on (most) of its projects, because internally 'they' know how a project is travelling, what labour recoveries can be applied and when. These are relatively easy to gauge when staff and projects are on the same site and have substantial project experience, whereas clients are offsite and don't have that intuitive feel for these projects. As a result, the curve capability is important but not so much for the internal stakeholder. Therefore the message that needs to be emphasised in rallying staff around the EVM approach needs to be centred on service providing to the client not improving LAP time management on routine projects.

This EVM application research has taken the method from a start point of zero utilisation and knowledge through the detailed workings to enable successful application of the method on all singular projects selected for investigation. It then extended its application journey into the host organisation seeking data needs and shaping the support systems. The final phases were concerned with integrating the tool's structural foundation to develop a PMS that shifted the application value to the portfolio level for this particular project environment, as a result the research found its way into developing organisational functions and operations activities using EVM data streams as a central theme to measuring both project and organisational status. Consequently, it is accepted that EVM is a powerful process that has the capability to offer SME's in the manufacturing sector a practical tool that can be moulded to suit the operational cycle and deliver project information for better project and organisational management. However its application must be considered in the context of the target project environment. It needs to be tailored to the scale of the task at hand rather than taking a one-
size-fit-all approach by applying EVM's traditional scope where a net value may not be attainable.

### 6.2 Project Management in Business

Conclusions in respect of EVM application (Section 6.1) drew in many elements of discussion relating to the organisation. This was a result of the application research influencing the organisation's structure as concepts from literature were applied in the development of the PMS. Therefore aspects from these preceding comments have relevance to this section at least in part. However there are broader business outcomes that relate to the research and had a bearing on the host organisation's relationship with the research effort. As a result, these outcomes form an important sub-discussion to the main application theme, as they are related to the subject of project management in business but also draw on the EVM frame-work that shaped the organisational outcomes for much of their development.

Over the course of the research period (Jan 2009 to Dec 2012) the business climate of the host organisation (LAP) changed considerably. To re-call introductory discussions from Section 1.1, in the decade leading up to this research LNG 'green field' projects had contributed significantly to the host's business activities. However through innovative development in construction methods coupled to a global approach to engineering and procurement for these projects, the market had moved in a way that meant the host organisation could no longer offer competitive or complete supply, in part due to work package sizes being requested. These trends had also influenced other sectors that were concerned with major projects, in all the organisation was faced with a market that was shifting its manufacturing priorities. As a result the research proposal was influenced by these business developments. Project management with EVM adaption was considered a promising strategy to pursue in seeking to differentiate locally manufactured pressure equipment, because it was associated with service providing rather than the physical product where it was difficult to directly compete.

EVM was selected as a base to work from because of its relationship with good project management practice and offered a project status communication tool that had not yet entered pressure equipment supply chain at this level. Needless-to-say projects completed by pressure equipment suppliers were frequently delayed and knock-on effects were becoming more significant with concurrent engineering utilised in equipment design, reducing toleration of
slippage as manifested in the greater commercial penalty conditions imposed for delay. It was also perceived that EVM promoted best practice in project control. This attribute is considered as an increasingly important area of the business to address given increasing market competition and the reduction in margins available for management reserves. Therefore project finance controls also needed to become part of the strategies for business improvements, aimed at internal management processes.

In consequence, the overall object of the research was to find a means of offering better project management practices for use in smaller oil \& gas projects such as 'brown field' developments and plant refurbishments. It was considered that in these projects, normally run by local end users rather than offshore EPCM providers, clients would see value in strategies being applied to enhance project services to better manage schedule risks on these smaller schedule-intensive plant upgrade projects. These projects were viewed as small enough to warrant the higher local manufacturing cost when weighed up against offshore management costs with respect to the products end price. In short this business strategy was seeking a niche market that best practice project management services would add value to and was an attainable competitive edge the host organisation could work towards with minimal capital investment required.

As discussed in Section 6.1 by introducing EVM to the organisation it forced major organisational change that was driven by the basic needs of EVM seeking data for performance measurement. This grass-roots review of organisational processes within functions and assessing the networks between functions that collectively contributed to delivering projects became the catalyst for a shift in the organisation's view of project management and its relationship to the business environment. The core activities of the business were now seen as delivering projects rather than delivering products, this re-focused effort on processes and systems as well as control of such business elements with the intention of delivering better projects. The change in mindset aligned well with EVM's concepts of providing raw data for measuring project effort against planned commitments. By extending these concepts, project data began to be used to measure portfolio status, this evolved into a tool that assisted production to understand the portfolio load week by week with respect to labour commitment and task completion for the week. Refinement of the project to production monitoring process, led to the development of similar weekly project-to-organisation reviews that at the conclusion of this research is promoting a second major
change in the organisation's project management methodology seeking better alignment with project delivery functions and matching these with the human resource skills available to the organisation.

It could be argued that reforms could have come from business or production management research and applied strategies resulting in similar outcomes for the business. However it is believed the association with EVM had two fundamental benefits that have guided the development process to achieve a robust project management system. Initially the specific requirements for raw data and tight control of the systems that deliver this information has ensured development remains closely aligned to both organisational processes and data associated with performance review, it also has ensured the form of the data is project assessment orientated. The second relevant aspect is the fact that EVM is a project management orientated tool, therefore its methodologies are attuned to the project environment. Given the host organisation's core business is project delivery there is a high degree of client involvement in product design, manufacture and delivery. As a result clients can become embedded in the projects life cycle within the bounds of the host organisation. If development of these systems was taken from the business or production frame it may not have delivered the same project-centred association. It is speculated that this development angle would be less adaptable to dealing with the clients presence in the project, as both of these practices are assumed to have an internal only process methodology that would most likely baulk at product development or physical manufacture in collaboration with external parties.

The resultant business structure that has been shaped by this research, while still in a maturing phase, is producing results for the host organisation with respect to capturing the attention of brown-field developers. The expectation that advanced project management services would be considered as value added by these project operators is coming to fruition. While there is much work to be done on the interface between EVM and the management of the singular project, the scope within the OPM3 frame as well as the more recent organisational context, the foundations that have been used to date for communicating the organisation strategies for improvement have been received well by the host's client base.

### 6.3 Research Value

Engineering as a profession, has responsibilities in shaping science and technology for practical application. Research within this realm can explore theories to derive new applications or it can take existing applications and push them further. Such work can be approached from an academic front or through industry needs, resulting in a top down or bottom up development strategy respectively. This research program has been developed through industry needs, tackling managerial based business problems using existing theories and taking further a specific application tool (EVM). The industry partnering program under which this research has been made possible has been able to capture practical application experiences from a live business environment and analyse these through the prism of relevant present day project management literature and theories.

The special value from this research derives from the industry setting. Opening up a live business for investigation to the level done by this research is only possible where there is a unique alignment between: willingness of the host organisation, acceptance by the educational institution, approval by the industry partnering program, capacity by the researcher who also needed to have an intimate knowledge of host's business activities and a commercial environment that has presented a situation to warrant research commitment. The collective synergy of the parties coupled to the resulting application outcomes, delivers value to this particular manufacturing sector at a time where innovation is an important tool for addressing business climate changes.

### 6.3.1 Contribution and Strengths

While research value lies with the industry setting and its application outcomes, the contribution of the research is aligned with the information this work has assembled in regard to the application of EVM and to organisational project management in the small business environment. Project management research is commonly initiated at the academic level seeking assessment of methods with respect to practitioner responses. The bottom up approach this research takes on, while not unique, contributes to the smaller research pool that is fed by practitioners' researching solutions from the more abstract academic body of knowledge.

Specifically, contributions are delivered in framing project modelling literature in the context of this small project management application. Equally the application of EVM in a non-
traditional setting appears to be timed well with the current push for: EVM simplification, a re-connection with its industrial beginnings, the broader view of its usefulness on the small project and finally the acceptance the method is gaining globally.

The documented influences EVM has had on the organisation and the commercial push by the host business to develop project management services contributes to more recent literature threads discussing organisational project management in businesses. The experiences and outcomes from the research have a good correlation with these developing theories and are considered complementary to the vision that project management is a management tool in its own right where the context of the business in question is centred on delivering projects.

### 6.3.2 Limitations and Weaknesses

The singular organisational setting is an obvious research limitation as issues and solutions are specific to one business case. Despite this, such business and EVM application problems would be transferable. Although the details in the research are specific to this application case the underlying concepts would for the most part be recognisable to other business settings, and therefore could be utilised for investigations into similar problems.

The scope of this research required re-configuring of the host organisation, as a necessary stage in the objective of applying EVM, therefore the research as a completed work needed to cover these endeavours in reasonable detail. As a result the specific details for each and every project sample examined with respect to modelling PV, EV and AC allocation was not feasible to include in the time frame or document scope. While the strategies used for application of each of these terms were described, it is acknowledged that to contribute in fine detail to the response of the project and forecasting curves there needs to be a very detailed breakdown of how costs were allocated to each of these dependent variables and their relationship with the project structure and history.

Putting aside the desire to examine EVM's response to these projects at a micro level, the results provide sufficient information to be able to identify aspects of application that can be subject to further more detailed examination. In all, the research was about the application of EVM, and through this process it was found the method cannot function in isolation. It requires a suitable PMS and an organisational structure that will support the tool. Therefore
these broader issues are important elements in responding to the research purpose and in adequately addressing them, it has been necessary to limit the coverage of the specific curve response questions.

### 6.4 Further Research

Further research is addressed in two contexts one related to the host organisation and the unfinished work at the conclusion to this research. The other relates to the wider academic aspect of the research and its place in the project management and EVM domains.

At the conclusion of this research, the host organisation is in the middle of major changes, many being driven by this research, others in response to the external business environment. Further work with respect to organisational EVM adaption is aimed at testing project response in more detail so as to establish a benchmark for project outputs. This will then be used to shift EVM application across to a commercial software tool that can hopefully combine scheduling with resource loading and EVM outputs can be validated against the models developed from first principles by this research. The second phase of further work will be to address the EVM acceptance phase, initially by training applicable staff in EVM application, establishing EVM application on projects that would benefit (be it for internal or external benefit). The final stage in acceptance will be to embed regular project reporting practice to both internal and external stakeholders. Formalising these final application aspects will enable the matured PMS to be documented as part of the organisations ISO 9001 business structure.

Further work in the context of general research, would have specific benefit to this application from further collaboration with recent research threads by Lipke regarding the short duration projects and their 'stop-work' or 'down-time' tendencies and the effects of schedule structure (Lipke 2011a, 2011b, 2012). In conjunction with Lipke, who draws on concepts constructed by Vanhoucke \& Vandevoorde ${ }^{32}$, there is also interest in investigating their own developments in schedule topology and project modelling using these manufacturing projects to better understand both ' S ' curves and forecasting response at a micro level. Further work on this specific aspect of EVM would contribute to an area that this

[^22]research was not able to explore due to its broader scope, but could be pursued now that organisational application issues have been resolved.

### 6.5 Chapter Summary

EVM has evolved almost a full circle, antecedents starting in industrial age factories as a planning tool, moving to a cost and schedule control tool, then a system. The desire for wider utilisation shifted it to a position that entailed regulation ${ }^{33}$ to the point where its acceptance was challenged in the wider private business sector. Current views are seeking to wind the method back to its roots since the basic form, as originally intended, has value at any level of application.

While simplification is the new vision of EVM, its application has an inseparable link to supporting organisational structure and skills when being applied to an environment that embraces both project and operational management. The method requires both data support and knowledge of modelling to be in place before benefits can be achieved with certainty.

The application process requires a series of phases to be accomplished that enables the method to translate from an independent tool to an embraced system (even at a simple level). The connections required to bring EVM to life draw from two domains one engages with the details of the project and its representation within EVM. The other is embedded in the relationship between the methods access to information and the supporting organisation. Although EVM is considered a simple model in the wider scheme of project modelling, successful application requires a methodological building up of its capabilities.

[^23]The phases of transition from application to acceptance ${ }^{34}$ are summarised as:

- Application - Resolves the details between the project in hand and EVM fundamentals for operation.
- Adaption - Resides within the application but is concerned with levels of EVM operators. These are used to identify where simplification and flexibility can be included for the next two phases.
- Integration - Deals with the EVM, as a working entity, and its interface with the organisation it is to become part of.
- Acceptance - Addressing the user needs and their responses to the systems design. This phase is not effectively achieved without the underlying phases having solid form and function. Although the scope of this phase may only appear to entail window dressing, the essence is significant as it is the pathway to system uptake.

The approach to EVM application can be beneficial if the process is undertaken in simple incremental steps providing opportunity to identify and assess the many relationships between EVM and the organisation. This provides the opportunity to appreciate these connections and understand the effects they have on the method as it moves through the phases of maturity. Using this approach there is opportunity to identify and adjust system rigidity and flexibility from the adaption phase onward. Inclusions of these elements are necessities for successful completion through to the acceptance.

This research had a specific business objective to add value to the end products of the host organisation. This was sought by improving project management services using EVM's association with best practice in project control. The need for achieving better project delivery was due to external business changes in the host's industry market. The outcomes for the business were plentiful as EVM penetrated the organisation. The methods need for structure forced numerous detailed reviews of business process, functions and the networking between them to deliver its projects. The overall net benefits that developed far exceeded the initial isolated project management targets envisaged. As a result the object of addressing

[^24]market changes is being realised, through innovative application of the broader EVM-based benefits that are coupled to organisational structure and good project management practices.

The value from this research comes from the industry setting. Access to a live business for investigation to the level done by this research is only possible where there is a unique alignment between the various parties to deliver practical application under an academic research program. In addition researching actual projects where application can be progressively refined and analysed is a research process that cannot be created 'off the shelf', project exhibits only become available for study when commercial opportunities exist. As a result of this practice-based research, the experience and lessons in applying academic theories to the live project environment provides a testing ground for the theoretical body of knowledge for further utilisation.

While research value lies with the industry setting the contribution is aligned with the information this work has assembled in regard to the application of EVM and organisational project management in the small business environment. The application of EVM in a nontraditional setting contributes to the current push for EVM simplification and a re-connection with its industrial beginnings.

Research limitations arise from the fact investigations and outcomes were based on a singular business environment and therefore may be limited in some respects. However it is common for treatments of business problems, (be it for EVM or general management) to be transferable between businesses in similar industries. Therefore the experiences and discussions are expected to be of value to a wider audience despite the singular sample. A second limitation noted is the fact that although strategies used for application in each of the EVM measures (PV, EV and AC) were described, the finer numerical details were not part of the analysis. This was due to the research being associated with application at an organisational level, therefore such details were beyond practical inclusion. This would limit how much can be gleaned from scrutinising the curves with respect to actual modelling details. However the results as presented provide sufficient information to be able to identify aspects of application that can be subject to further more detailed examination.

Further work in the context of general research, would have specific benefit to this application from further collaboration with recent research threads by Lipke (2011a, 2011b,
2012) regarding the short duration projects and their 'stop-work' or 'down-time' tendencies and the effects of schedule structure on forecasting in this environment.

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## A. Appendix A - Project Schedules

A1 Scheduling Method
A2 Project T001 - Schedule, Task Level
A3 Project T002 - Schedule, WP Level
A4 Project T003 - Schedule, WP Level
A5 Project T004 - Schedule, WP Level
A6 Project T005 - Schedule, WP Level
A7 Project 'S' Series - Schedule, Task Level

## A. 1 Scheduling Method

## A.1. 1 Software and Application

Schedules have been created in Microsoft Project $2003^{\circledR}$, as the current scheduling tool available for LAP. Scheduling is presently used solely to plan the project in a time scale, to map out the WBS and identify the critical path. Resource loading or levelling and cost modelling currently do not form part of this process. Following completion of this research it is desirable to utilise a later version of this tool (or equivalent option) to combine resources and cost in pursuit of a singular project planning tool.

## A. 2 Project T001 - Schedule, Task Level







Appendix A - Project Schedules

## A. 3 Project T002 - Schedule, WP Level



Appendix A - Project Schedules
A. 4 Project T003 - Schedule, WP Level


Appendix A - Project Schedules
A. 5 Project T004 - Schedule, WP Level



Appendix A - Project Schedules

## A. 6 Project T005 - Schedule, WP Level




Appendix A - Project Schedules
A. 7 Project 'S' - Schedule, Task Level




## B. Appendix B - Time Phase Budget

B1 Typical Monthly TPB Sample

## B. 1 Typical Monthly TPB Sample and Calculations

Part 1 - Upper two (Engineering and Material / Services) Groups
Monthly Time Phase Budget Sample

| Activities from WBS |  | February |  |  |  |  | Summary of Totals |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | upto 22/2/12 | 23/2 to 14/3 | 22/3 to 11/4 | 12/4 to 9/5 | 10/5 to 30/5 | $\sum$ for Row | $\sum$ from PB |
| Admin \& Engineering |  |  |  |  |  |  | \$0.00 | \$0.00 |
|  | N/A |  |  |  |  |  | \$0.00 |  |
|  | N/A |  |  |  |  |  | \$0.00 |  |
|  | N/A |  |  |  |  |  | \$0.00 |  |
|  | N/A |  |  |  |  |  | \$0.00 |  |
|  | N/A |  |  |  |  |  | \$0.00 |  |
| Material \& Services |  |  |  |  |  |  | \$46,600.00 | \$46,600.00 |
|  | Heads Blanks |  | \$9,300.00 |  |  |  | \$9,300.00 | \$9,300.00 |
|  | Head Forming |  |  | \$7,840.00 |  |  | \$7,840.00 | \$7,840.00 |
|  | Shell Plates |  | \$15,700.00 |  |  |  | \$15,700.00 | \$15,700.00 |
|  | Profile, Section \& Misc |  | \$820.00 |  |  |  | \$820.00 | \$820.00 |
|  | NDE \& Testing |  |  | \$2,000.00 | \$2,000.00 |  | \$4,000.00 | \$4,000.00 |
|  | N/A |  |  |  |  |  | \$0.00 | \$0.00 |
|  | Fasteners |  | \$160.00 |  |  |  | \$160.00 | \$160.00 |
|  | Gaskets |  | \$120.00 |  |  |  | \$120.00 | \$120.00 |
|  | N/A |  |  |  |  |  | \$0.00 | \$0.00 |
|  | Painting |  |  |  |  | \$6,700.00 | \$6,700.00 | \$6,700.00 |
|  | Heavy Transport |  | \$880.00 | \$240.00 |  | \$480.00 | \$1,600.00 | \$1,600.00 |
|  | Transport to Site |  |  |  |  |  | \$0.00 | \$0.00 |
|  | Misc (Int Delivery, name plate etc) |  |  |  |  | \$160.00 | \$160.00 | \$160.00 |
|  | Shop Consumables \& Hydro |  |  |  | \$200.00 |  | \$200.00 | \$200.00 |
|  | Contracted PWHT |  |  |  |  |  | \$0.00 | \$0.00 |

Part 2 - Lower (Labour) Groups, Sub-Totals and Reporting Period

| Activities from WBS | February |  |  |  |  | Summary of Totals |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | upto 22/2/12 | 23/2 to 14/3 | 22/3 to 11/4 | $12 / 4$ to 9/5 | 10/5 to 30/5 | $\Sigma$ for Row | $\sum$ from PB |
| TPB Manufacture <br> (Work Description Cells - Repesentation of the Labour Budget) |  |  |  |  |  | \$18,000.00 | \$18,000.00 |
| Pre-Fabrication - Nozzles |  | \$360.00 | \$2,880.00 |  |  | \$3,240.00 | \$3,240.00 |
| Pre-Fabrication - Attachments |  | \$3,600.00 | \$720.00 |  |  | \$4,320.00 | \$4,320.00 |
| Strakes - Roll \& weld strakes |  |  | \$2,160.00 |  |  | \$2,160.00 | \$2,160.00 |
| Assemble - strakes \& end |  |  | \$720.00 | \$1,080.00 |  | \$1,800.00 | \$1,800.00 |
| Fitout - Nozzles \& internal attachments |  |  |  | \$1,800.00 |  | \$1,800.00 | \$1,800.00 |
| Closing - End \& weld |  |  |  | \$1,080.00 |  | \$1,080.00 | \$1,080.00 |
| Finishing - External attachments |  |  |  | \$1,080.00 |  | \$1,080.00 | \$1,080.00 |
| Testing - Hydro test, dressing \& load |  |  |  | \$1,800.00 |  | \$1,800.00 | \$1,800.00 |
| FI \& Pack - Dress \& close |  |  |  |  | \$720.00 | \$720.00 | \$720.00 |
| Planned Value - Period ( $\mathrm{PV}_{\mathrm{P}}$ ) | \$0.00 | \$30,940.00 | \$16,560.00 | \$9,040.00 | \$8,060.00 | TPB BAC | \$64,600.00 |
| Planned Value - Cummulative (PV) | \$0.00 | \$30,940.00 | \$47,500.00 | \$56,540.00 | \$64,600.00 | Project BAC | \$64,600.00 |
| Engineering \& QA Effort | 0 | \$0.00 | \$0.00 | \$0.00 | \$0.00 | \$0.00 | Indirect |
| Actual Labour Cost | 0 | \$2,565.00 | \$10,170.00 | \$7,605.00 | \$0.00 | \$20,340.00 | Direct |
| Actual Material Cost | 0 | \$10,417.00 | \$27,528.00 | \$3,154.00 | \$11,379.00 | \$52,478.00 | Materials |
| Reporting date for the period | 23/02/12 | 15/03/12 | 12/04/12 | 10/05/12 | 31/05/12 | \$72,818.00 | Project Cost (PC) |
| Report \# (Project Months) | 0 | 1 | 2 | 3 | 4 | Rounded $\mathrm{PD}_{\mathrm{R}}$ | 4 |
|  |  |  |  |  |  | Rounded $\mathrm{AD}_{\mathrm{R}}$ | 4 |

Part 3 - PV, EV and AC Period Totals and Cumulative Results

| Performance Measurement |  | nce |  |  |  |  | Row total |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | February |  |  |  |  |  |
|  |  | upto 22/2/12 | 23/2 to 14/3 | 22/3 to 11/4 | 12/4 to 9/5 | 10/5 to 30/5 |  |
| Planned Value - Period ( $\mathrm{PV}_{\mathrm{P}}$ ) | Earned Value - Period (EVP) | \$0.00 | \$30,940.00 | \$16,560.00 | \$9,040.00 | \$8,060.00 | \$64,600.00 |
|  |  | \$0.00 | \$11,981.96 | \$30,130.59 | \$10,385.81 | \$12,101.64 | \$64,600.00 |
| Actual Cost - Period (ACP) |  | \$0.00 | \$12,982.00 | \$37,698.00 | \$10,759.00 | \$11,379.00 | \$72,818.00 |


| Cumulative Performance |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Curve Data | February |  |  |  |  |
|  | upto 22/2/12 | 23/2 to 14/3 | 22/3 to 11/4 | 12/4 to 9/5 | 10/5 to 30/5 |
| Planned Value (PV) | \$0.00 | \$30,940.00 | \$47,500.00 | \$56,540.00 | \$64,600.00 |
| Earned Value (EV) | \$0.00 | \$11,981.96 | \$42,112.55 | \$52,498.36 | \$64,600.00 |
| Actual Cost (AC) | \$0.00 | \$12,982.00 | \$50,680.00 | \$61,439.00 | \$72,818.00 |
| Schedule Variance ( $\mathrm{SV}_{\mathrm{t}}$ ) | 0.00 | -0.61 | -0.33 | -0.45 | 0.00 |
| Planned Value (PV) as \% | 0.0\% | 47.9\% | 73.5\% | 87.5\% | 100.0\% |
| Earned Value (EV) as \% | 0.0\% | 18.5\% | 65.2\% | 81.3\% | 100.0\% |
| Actual Cost (AC) as \% | 0.0\% | 20.1\% | 78.5\% | 95.1\% | 112.7\% |
| Actual Time as \% of $\mathrm{PD}_{\mathrm{R}}$ | 0.0\% | 25.0\% | 50.0\% | 75.0\% | 100.0\% |
| Reporting Date | 23/02/12 | 15/03/12 | 12/04/12 | 10/05/12 | 31/05/12 |

Part 4a - PMI Method Calculations (Set A)
Schedule Analysis \& Forecasting using PMI
(Calculations using PMI Theories from Practice Standard for EVM)

| PMI, Std Practice for EVM - Measurement Tools | February |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  | upto 22/2/12 | 23/2 to 14/3 | 22/3 to 11/4 | $12 / 4$ to 9/5 | 10/5 to 30/5 |
| Actual Time - Months <br> AT $=$ Project months till completion (maxium value $=A D_{R}$ ) | 0 | 1 | 2 | 3 | 4 |
| $\begin{array}{rr} \text { Planned Time } \\ P T=E V \geq P V\left(\text { maximum value }=P D_{R} @ A D_{R}\right) \end{array}$ | 0 | 0 | 1 | 2 | 4 |
| Schedule Variance (\$) SV = EV - PV | \$0.00 | -\$18,958.04 | -\$5,387.45 | -\$4,041.64 | \$0.00 |
| Schedule Variance (\%) $\mathrm{SV}_{\%}=\mathrm{SV} / \mathrm{PV}$ | 0.00\% | -61.27\% | -11.34\% | -7.15\% | 0.00\% |
| Schedule Variance (months) $S V_{\text {PMIt }}=$ PT - AT | 0 | -1 | -1 | -1 | 0 |
| Schedule Variance (\%) $\mathrm{SV}_{\text {PMIt }}=$ SV $_{\text {PMIt }} /$ AT | 0.00\% | -100.00\% | -50.00\% | -33.33\% | 0.00\% |
| Schedule Performance Index (\$) SPI $=\mathrm{EV} / \mathrm{PV}$ | 1.00 | 0.39 | 0.89 | 0.93 | 1.00 |
| Schedule Performance Index (months) SPI $_{\text {PMIt }}=$ PT / AT | 1.00 | 0.50 | 0.50 | 0.67 | 1.00 |
| Estimate at Completion (months) using $\mathrm{SPI}_{\$}$ $\mathrm{EAC}_{\mathrm{t}}=(\mathrm{BAC} / \mathrm{SPI}) /\left(\mathrm{BAC} / \mathrm{PD}_{\mathrm{R}}\right)$ | 4.00 | 10.33 | 4.51 | 4.31 | 4.00 |
| Estimate at Completion (months) <br> $\mathrm{EAC}_{\text {PMIt }}=\left(\mathrm{BAC} / \mathrm{SPI}_{\text {PMIt }} /\right.$ / (BAC / PD $\left.\mathrm{R}_{\mathrm{R}}\right)$ | 4.00 | 8.00 | 8.00 | 6.00 | 4.00 |
| $\begin{aligned} & \text { Cost Variance (\$) } \\ & \text { CV = EV - AC } \\ & \hline \end{aligned}$ | \$0.00 | -\$1,000.04 | -\$8,567.45 | -\$8,940.64 | -\$8,218.00 |
| $\begin{aligned} & \text { Cost Variance (\%) } \\ & \mathrm{CV}_{\%}=\mathrm{CV} / \mathrm{EV} \end{aligned}$ | 0.00\% | -8.35\% | -20.34\% | -17.03\% | -12.72\% |
| $\begin{aligned} & \text { Cost Performance Index (\$) } \\ & \text { CPI = EV / AC } \end{aligned}$ | 1.00 | 0.92 | 0.83 | 0.85 | 0.89 |
| To Completion Performance Index (\$) TCPI = (BAC - EV) / (BAC - AC) | 1.00 | 1.02 | 1.62 | 3.83 | 0.00 |
| Estimate at Completion (\$) $\mathrm{EAC}=\mathrm{BAC} / \mathrm{CPI}$ | \$64,600.00 | \$69,991.65 | \$77,742.34 | \$75,601.59 | \$72,818.00 |
| Variance at Completion (\$) $V A C=B A C-E A C$ | \$0.00 | -\$5,391.65 | -\$13,142.34 | -\$11,001.59 | -\$8,218.00 |
| $\begin{aligned} & \text { Variance at Completion (\%) } \\ & \text { VAC \% VAC / BAC } \end{aligned}$ | 0.00\% | -8.35\% | -20.34\% | -17.03\% | -12.72\% |
| Estimate to Complete (\$) $E T C=(B A C-E V) / C P I$ | \$64,600.00 | \$57,009.65 | \$27,062.34 | \$14,162.59 | \$0.00 |

## Part 4b - PMI Method Calculations (Set B)

## Schedule Analysis \& Forecasting using PMI

(Calculations using PMI Theories from Practice Standard for EVM)

| PMI, Std Practice for EVM - Measurement Tools | February |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | upto 22/2/12 | 23/2 to 14/3 | 22/3 to 11/4 | 12/4 to 9/5 | 10/5 to 30/5 |  |
| Estimate at Completion (\$) using j,k (BM $\downarrow$ ) <br> $E A C_{j, k}=A C+\left[(B A C-E V) /\left(\left(E V_{j}+E V_{k}\right) /\left(A C_{j}+A C_{k}\right)\right]\right.$ | \$64,600.00 | \$69,991.65 | \$77,144.72 | \$75,780.10 | \$72,818.00 |  |
| Estimate at Completion (\$) using $\mathrm{i}, \mathrm{j}, \mathrm{k}(\mathrm{BM})$ $E A C_{i, j, k}=A C+\left[(B A C-E V) /\left(\left(E V_{i}+E V_{j}+E V_{k}\right) /\left(A C_{i}+A C_{j}+A C_{k}\right)\right)\right]$ | \$64,600.00 | \$69,991.65 | \$77,144.72 | \$75,641.90 | \$72,818.00 |  |
| Estimate at Completion (\$) using h,i,j,k (BM $\uparrow$ ) <br> $E A C_{h, i, j, k}=A C+\left[(B A C-E V) /\left(\left(E V_{h}+\ldots+E V_{k}\right) /\left(A C_{h}+\ldots+A C_{k}\right)\right)\right]$ | \$64,600.00 | \$69,991.65 | \$77,144.72 | \$75,641.90 | \$72,818.00 |  |
| Estimate at Completion (\$) using g,h,i,j,k (BM $\uparrow \uparrow)$ <br> $E A C_{g . h, i, j, k}=A C+\left[(B A C-E V) /\left(\left(E V_{g}+\ldots+E V_{k}\right) /\left(\mathrm{AC}_{\mathrm{g}}+\ldots+\mathrm{AC}_{\mathrm{k}}\right)\right)\right]$ | \$64,600.00 | \$69,991.65 | \$77,144.72 | \$75,641.90 | \$72,818.00 |  |
| Estimate at Completion (\$) using product of CPI \& SPI $E A C_{C P I . S P I}=A C+[(B A C-E V) /(C P I \times S P I)]$ | \$64,600.00 | \$160,193.18 | \$81,204.42 | \$76,691.92 | \$72,818.00 |  |
| Estimate at Completion (\$) using product of CPI \& SPI -PMIt $\mathrm{EAC}_{\text {CPI.SPI-PMIt }}=\mathrm{AC}+[(\mathrm{BAC}-\mathrm{EV}) /(\mathrm{CPI} \times \text { SPI-PMIt })]$ | \$64,600.00 | \$127,001.30 | \$104,804.68 | \$82,682.89 | \$72,818.00 | $\mathrm{CPI}_{\mathrm{f}} \& \mathrm{SPI}_{\mathrm{f}}$ Factors for EAC calculations |
| Estimate at Completion (\$) using sum of CPI \& SPI factored (variable) $\mathrm{EAC}_{\mathrm{CPI.SPIfv}}=\mathrm{AC}+\left[(\mathrm{BAC}-\mathrm{EV}) /\left(\mathrm{CPI}_{\mathrm{f}}^{*} \mathrm{CPI}+\mathrm{SPI}_{\mathrm{f}}^{*} \mathrm{SPI}\right)\right]$ | \$64,600.00 | \$77,478.59 | \$77,384.77 | \$75,360.35 | \$72,818.00 | $\mathrm{CPI}_{\mathrm{f}}=0.8$ |
| Estimate at Completion (\$) using sum of CPI \& SPI _PMIt $^{\text {factored (variable) }}$ $\mathrm{EAC}_{\text {CPI.SPI-PMIIIV }}=\mathrm{AC}+\left[(\mathrm{BAC}-\mathrm{EV}) /\left(\mathrm{CPI}_{\mathrm{f}}^{*} \mathrm{CPI}+\text { SPI }_{\mathrm{f}}^{*} \mathrm{SPI}_{\text {-PMII }}\right)\right]$ | \$64,600.00 | \$75,744.03 | \$80,084.58 | \$76,252.80 | \$72,818.00 | $\mathrm{SPI}_{\mathrm{f}}=0.2$ |
| Estimate at Completion (\$) using sum of CPI \& SPI factored (weighted to CPI) $E A C_{\text {CPIfw.SPI }}=A C+\left[(B A C-E V) /\left(0.8^{*} C P I+0.2^{*}\right.\right.$ SPI $\left.)\right]$ | \$64,600.00 | \$77,478.59 | \$77,384.77 | \$75,360.35 | \$72,818.00 |  |
| Estimate at Completion (\$) using sum of CPI \& SPI factored (balanced) $E A C_{\text {CPI.SPIfi }}=\mathrm{AC}+\left[(\mathrm{BAC}-\mathrm{EV}) /\left(0.5^{*} \mathrm{CPI}+0.5^{*} \mathrm{SPI}\right)\right]$ | \$64,600.00 | \$93,300.68 | \$76,865.80 | \$75,013.50 | \$72,818.00 |  |
| Estimate at Completion (\$) using sum of CPI \& SPI factored (weighted to SPI) $\mathrm{EAC}_{\mathrm{CPI} . \text { SPIfw }}=\mathrm{AC}+\left[(\mathrm{BAC}-\mathrm{EV}) /\left(0.2^{*} \mathrm{CPI}+0.8^{*} \mathrm{SPI}\right)\right]$ | \$64,600.00 | \$119,409.00 | \$76,366.62 | \$74,683.52 | \$72,818.00 |  |
| Estimate at Completion (\$) using sum of CPI \& SPI.-PMIf factored (weighted to CPI) $E A C_{\text {CPIIf.SPI-PMIt }}=\mathrm{AC}+\left[(\mathrm{BAC}-\mathrm{EV}) /\left(0.8^{*} \mathrm{CPI}+0.2^{*} \mathrm{SPI}_{\text {-PMIt }}\right)\right]$ | \$64,600.00 | \$75,744.03 | \$80,084.58 | \$76,252.80 | \$72,818.00 |  |
| Estimate at Completion (\$) using sum of CPI \& SPI.-pMIt factored (balanced) $E A C_{\text {CPI.SPI.PMItfo }}=\mathrm{AC}+\left[(\mathrm{BAC}-\mathrm{EV}) /\left(0.5^{*} \mathrm{CPI}+0.5^{*}\right.\right.$ SPI_-pmit $\left.)\right]$ | \$64,600.00 | \$86,937.38 | \$84,471.58 | \$77,350.22 | \$72,818.00 |  |
| Estimate at Completion (\$) using sum of CPI \& SPI_-PMIt factored (weighted to SPI_-pmit $\mathrm{EAC}_{\text {CPI.SPI.-PMItfw }}=\mathrm{AC}+\left[(\mathrm{BAC}-\mathrm{EV}) /\left(0.2^{*} \mathrm{CPI}+0.8^{*} \mathrm{SPI}_{\text {-PMIt }}\right)\right]$ | \$64,600.00 | \$102,989.92 | \$90,397.15 | \$78,623.24 | \$72,818.00 |  |
| Estimate at Completion (\$) using sum of CPI \& SPI factored (weighted to $\mathrm{SPI}_{\mathrm{t}}$ ) $E A_{\text {CPI.SPIIfw }}=A C+\left[(B A C-E V) /\left(0.2^{*} \mathrm{CPI}+0.8^{*} \mathrm{SP} \mathrm{I}_{\mathrm{t}}\right)\right]$ | \$64,600.00 | \$119,409.00 | \$77,576.99 | \$75,648.26 | \$72,818.00 |  |

## Part 4c - PMI Method Calculations (Set C)

Schedule Analysis \& Forecasting using PMI

| PMI, Std Practice for EVM - Measurement Tools | February |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  | upto 22/2/12 | 23/2 to 14/3 | 22/3 to 11/4 | 12/4 to 9/5 | 10/5 to 30/5 |
| Forecast of Project Cost (PC) as \% using EAC (EAC / PC) | 88.7\% | 96.1\% | 106.8\% | 103.8\% | 100.0\% |
| Forecast of Project Cost (PC) as \% using EAC ${ }_{j}$ ( (BM $\downarrow$ ) $E A C_{j, k} / P C$ | 88.7\% | 96.1\% | 105.9\% | 104.1\% | 100.0\% |
| Forecast of Project Cost (PC) as \% using EAC $\mathrm{i}_{\mathrm{i}, \mathrm{k}}$ (BM) (EAC $\mathrm{i}_{\mathrm{i}, \mathrm{k}} / \mathrm{PC}$ ) | 88.7\% | 96.1\% | 105.9\% | 103.9\% | 100.0\% |
| Forecast of Project Cost (PC) as \% using $\mathrm{EAC}_{\mathrm{h}, \mathrm{i}, \mathrm{l}, \mathrm{k}}$ (BM $\uparrow$ $E A C_{\text {hi, }, \mathrm{j}} / \mathrm{PC}$ | 88.7\% | 96.1\% | 105.9\% | 103.9\% | 100.0\% |
| Forecast of Project Cost (PC) as \% using EAC g., i, i,, k (BM $\uparrow \uparrow$ ) $E A C_{g . \text { n.i.j, }} / P C$ | 88.7\% | 96.1\% | 105.9\% | 103.9\% | 100.0\% |
| Forecast of Project Cost (PC) as \% using EAC CPI.SPI $\mathrm{EAC}_{\text {CPI.SPI }} /$ PC | 88.7\% | 220.0\% | 111.5\% | 105.3\% | 100.0\% |
| Forecast of Project Cost (PC) as \% using EAC CPI.SPI.-PMIt $^{\text {I }}$ EAC ${ }_{\text {CPI.SPI-PMII }} /$ PC | 88.7\% | 174.4\% | 143.9\% | 113.5\% | 100.0\% |
| Forecast of Project Cost (PC) as \% using EAC cPI.SPIIv $^{\text {I }}$ EAC CPI.SPIV / PC | 88.7\% | 106.4\% | 106.3\% | 103.5\% | 100.0\% |
| Forecast of Project Cost (PC) as \% using EAC CPI.SPI.-PMItrv $^{\text {I }}$ EAC CPI.SPL-PMIITV PC | 88.7\% | 104.0\% | 110.0\% | 104.7\% | 100.0\% |
| Forecast of Project Cost (PC) as \% using EAC CPIIf.SPI (weighted to CPI) $E A_{\text {CPIIW.SPI }} /$ PC | 88.7\% | 106.4\% | 106.3\% | 103.5\% | 100.0\% |
| Forecast of Project Cost (PC) as \% using EAC cpl.spitr (balanced) EAC CPI.SPII / PC | 88.7\% | 128.1\% | 105.6\% | 103.0\% | 100.0\% |
| Forecast of Project Cost (PC) as \% using EAC CPI.SPIIf (weighted to SPI) EAC CPI.SPIIW PC | 88.7\% | 164.0\% | 104.9\% | 102.6\% | 100.0\% |
| Forecast of Project Cost (PC) as \% using EAC CPIIw.SPI-PMII (weighted to CPI) EAC ${ }_{\text {cPliw.SPI.PMIt }}$ / PC | 88.7\% | 104.0\% | 110.0\% | 104.7\% | 100.0\% |
| Forecast of Project Cost (PC) as \% using EAC CPI.SPI-PMItrb (balanced) EAC CPI.SPI-PMItib / PC | 88.7\% | 119.4\% | 116.0\% | 106.2\% | 100.0\% |
| Forecast of Project Cost (PC) as \% using EAC CPI.SPI-PMItfw (weighted to SPI $_{\text {-PMII }}$ ) EAC CPI.SPl-PMItfw / PC | 88.7\% | 141.4\% | 124.1\% | 108.0\% | 100.0\% |
| Forecast of Project Cost (PC) as \% using EAC CPI.SPltiw (weighted to $\mathrm{SPI}_{\mathrm{t}}$ ) <br> $E A C_{\text {CPI.SPIIf. }} /$ PC | 88.7\% | 164.0\% | 106.5\% | 103.9\% | 100.0\% |
| Reporting Date | 23/02/12 | 15/03/12 | 12/04/12 | 10/05/12 | 31/05/12 |

Appendix B - Time Phase budget (TPB)
Part 5a - Earned Schedule Method Calculations (Set A)

## Schedule Analysis \& Forecasting using Lipke

(Earned Schedule \& Index Calculations using Lipke)

| Lipke, Earned Schedule - Forecasting Calculations | February |  | 22/3 to 11/4 | 12/4 to 9/5 | 10/5 to 30/5 |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  | upto 22/2/12 | 23/2 to 14/3 |  |  |  |
| Actual Time (AT) - Months | 0 | 1 | 2 | 3 | 4 |
| Whole Time Increment of PV $\mathrm{C}=\mathrm{AT} \text { for } \mathrm{EV}>=\mathrm{PV}$ | 0 | 0 | 1 | 2 | 4 |
| Numerator portion of PV increment earned $I_{N}=E V_{A T}-P V_{C}$ | \$0.00 | \$11,981.96 | \$11,172.55 | \$4,998.36 | \$0.00 |
| Denominator portion of PV increment earned $I_{D}=P V_{C+1}-P V_{C}$ | \$30,940.00 | \$30,940.00 | \$16,560.00 | \$9,040.00 | -\$64,600.00 |
| Earned Schedule $\mathrm{ES}=\mathrm{C}+\mathrm{I}_{\mathrm{N}} / \mathrm{I}_{\mathrm{D}}$ | 0.00 | 0.39 | 1.67 | 2.55 | 4.00 |
| Schedule Variance (months) $S V_{t}=E S-A T$ | 0.00 | -0.61 | -0.33 | -0.45 | 0.00 |
| Schedule Variance (\%) $\mathrm{SV}_{\mathrm{t} \%}=\mathrm{SV}_{\mathrm{t}} / \mathrm{AT}$ | 0.00\% | -61.27\% | -16.27\% | -14.90\% | 0.00\% |
| Schedule Performance Index (months) $S P I_{t}=E S / A T$ | 1.00 | 0.39 | 0.84 | 0.85 | 1.00 |
| Reporting Date | 23/02/12 | 15/03/12 | 12/04/12 | 10/05/12 | 31/05/12 |

Part 5b - Earned Schedule Method Calculations (Set B)
Forecasting Calculations using Lipke Theories

| Lipke, Earned Schedule - Forecasting Calculations | February |  | 22/3 to 11/4 | 12/4 to 9/5 | 10/5 to 30/5 |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  | upto 22/2/12 | 23/2 to 14/3 |  |  |  |
| EAC Forecast of Cost (\$), PMI method $E A C=B A C / C P I$ | \$64,600.00 | \$69,991.65 | \$77,742.34 | \$75,601.59 | \$72,818.00 |
| Forecast of AD (months) Simple Form ${ }^{E E A C} C_{S V t}=P D_{R}+\left(S V_{t} x-1\right)$ | 4.00 | 4.61 | 4.33 | 4.45 | 4.00 |
| Forecast of AD (months) Short Form equ $\mathrm{IEAC}_{\mathrm{t}}=\mathrm{PD}_{\mathrm{R}} / \mathrm{SPI}_{\mathrm{t}}$ | 4.00 | 10.33 | 4.78 | 4.70 | 4.00 |
| Forecast of AD (months) Long Form PF $=i, j(B M \downarrow)$ $I E A C_{\mathrm{t}, \mathrm{j}, \mathrm{k}}=\mathrm{AT}+\left[\left(\mathrm{PD}_{\mathrm{R}}-\mathrm{ES}\right) /\left(\left(\mathrm{ES}_{\mathrm{j}}+E S_{\mathrm{k}}\right) /\left(\mathrm{AT}_{\mathrm{j}}+\mathrm{A} T_{\mathrm{k}}\right)\right)\right]$ | 4.00 | 10.33 | 5.38 | 4.71 | 4.00 |
| Forecast of $A D$ (months) Long Form $P F=i, j, k(B M)$ $\mathrm{IEAC}_{\mathrm{t}, \mathrm{i}, \mathrm{j}, \mathrm{k}}=\mathrm{AT}+\left[\left(\mathrm{PD}_{\mathrm{R}}-\mathrm{ES}\right) /\left(\left(\mathrm{ES}_{\mathrm{i}}+E S_{\mathrm{j}}+\mathrm{ES}_{\mathrm{k}}\right) /\left(\mathrm{AT}_{\mathrm{i}}+\mathrm{A} T_{\mathrm{j}}+\mathrm{A} T_{\mathrm{k}}\right)\right)\right]$ | 4.00 | 10.33 | 5.38 | 4.88 | 4.00 |
| Forecast of AD (months) Long Form $\mathrm{PF}=\mathrm{h}, \mathrm{i}, \mathrm{j}, \mathrm{k}(\mathrm{BM} \uparrow)$ $I E A C_{\mathrm{t}, \mathrm{~h}, \mathrm{i}, \mathrm{k}}=\mathrm{AT}+\left[\left(\mathrm{PD}_{\mathrm{R}}-\mathrm{ES}\right) /\left(\left(\mathrm{ES}_{\mathrm{h}}+\ldots+\mathrm{ES}_{\mathrm{k}}\right) /\left(\mathrm{AT}_{\mathrm{h}}+\ldots+\mathrm{AT}_{\mathrm{k}}\right)\right)\right]$ | 4.00 | 10.33 | 5.38 | 4.88 | 4.00 |
| Forecast of $A D$ (months) Long Form $\mathrm{PF}=\mathrm{g}, \mathrm{h}, \mathrm{i}, \mathrm{j}, \mathrm{k}(\mathrm{BM} \uparrow \uparrow)$ $I E A C_{t, g, \mathrm{~h}, \mathrm{i}, \mathrm{j}, \mathrm{k}}=\mathrm{AT}+\left[\left(\mathrm{PD}_{\mathrm{R}}-\mathrm{ES}\right) /\left(\left(\mathrm{ES}_{\mathrm{g}}+\ldots+\mathrm{ES}_{\mathrm{k}}\right) /\left(\mathrm{AT}_{\mathrm{g}}+\ldots+\mathrm{AT} T_{\mathrm{k}}\right)\right)\right]$ | 4.00 | 10.33 | 5.38 | 4.88 | 4.00 |
| Forecast of $A D$ (months) Long Form $\mathrm{PF}=$ product of $\mathrm{CPI} \& \mathrm{SPI}_{\mathrm{t}}$ $I E A C_{t, I P}=A T+\left[\left(P D_{R}-E S\right) /\left(C P I \times S P I_{t}\right)\right]$ | 4.00 | 11.11 | 5.34 | 4.99 | 4.00 |
| $\begin{aligned} & \text { Forecast of AD (months) Long Form PF = sum of CPI \& SPI factored (variable) } \\ & \text { IEAC }_{t}, \mathrm{IF}=A T+\left[\left(\text { PD }_{\mathrm{R}}-E S\right) /\left(\text { CPI }_{\mathrm{f}}^{*} C P I+\text { SPI }_{\mathrm{f}}^{*} \mathrm{SPI}_{\mathrm{t}}\right)\right] \end{aligned}$ | 4.00 | 5.43 | 4.79 | 4.69 | 4.00 |
| Forecast of AD (months) Long Form PF = sum of CPI \& SPI factored (weighted CPI) $\mid E A C_{t, I F w C P I}=A T+\left[\left(P D_{R}-E S\right) /\left(0.8^{*} C P I+0.2^{*} S P P I_{t}\right)\right]$ | 4.00 | 5.43 | 4.79 | 4.69 | 4.00 |
| Forecast of AD (months) Long Form PF = sum of CPI \& SPI factored (balanced) $\mid E A C_{t, \mid \mathrm{Fb}}=\mathrm{AT}+\left[\left(\mathrm{PD}_{\mathrm{R}}-\mathrm{ES}\right) /\left(0.5^{*} \mathrm{CPI}+0.5^{*} \mathrm{SP}_{\mathrm{t}}\right)\right]$ | 4.00 | 6.51 | 4.79 | 4.70 | 4.00 |
| Forecast of AD (months) Long Form PF = sum of CPI \& SPI factored (weighted SPI ${ }_{t}$ ) $\mathrm{IEAC}_{\mathrm{t}, \mathrm{IFwSPlt}}=\mathrm{AT}+\left[\left(\mathrm{PD}_{\mathrm{R}}-\mathrm{ES}\right) /\left(0.2^{*} \mathrm{CPI}+0.8^{*} \mathrm{SPI}_{\mathrm{t}}\right)\right]$ | 4.00 | 8.31 | 4.78 | 4.70 | 4.00 |
| Forecast of AD (months) Long Form PF = sum of CPI \& SPI factored (weighted SPI) $I E A C_{\mathrm{t}, \mathrm{IFwSPI}}=\mathrm{AT}+\left[\left(\mathrm{PD}_{\mathrm{R}}-\mathrm{ES}\right) /\left(0.2^{*} \mathrm{CPI}+0.8^{*} \mathrm{SPI}\right)\right]$ | 4.00 | 8.31 | 4.66 | 4.58 | 4.00 |
| Forecast of AD (months) Long Form PF = sum of CPI \& SPI factored (weighted SPI -pmit $^{\text {}}$ ) $I E A C_{t, I F w S P I-P M I t}=A T+\left[\left(P D_{R}-E S\right) /\left(0.2^{*} C P I+0.8^{*} \text { SPI }_{\text {PMMIt }}\right)\right]$ | 4.00 | 7.18 | 6.11 | 5.05 | 4.00 |

## Part 5c - Earned Schedule Method Calculations (Set C)

Forecasting Calculations using Lipke Theories

|  | February |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Lipke, Earned Schedule - Forecasting Calculations | upto 22/2/12 | 23/2 to 14/3 | 22/3 to 11/4 | 12/4 to 9/5 | 10/5 to 30/5 |
| Forecast delivery date, using Short Form equ IEAC svit Date of order + IEAC SVt | 22/06/12 | 10/07/12 | 1/07/12 | 5/07/12 | 22/06/12 |
| Forecast Delivery Date, using Short Form equ IEAC ${ }_{t}$ Date of order + IEAC ${ }_{t}$ | 22/6/12 | 28/12/12 | 15/07/12 | 13/07/12 | 22/06/12 |
| Forecast Delivery Date, using Long Form equ $\mathrm{IEAC}_{\mathrm{t}, \mathrm{j}, \mathrm{k}}(\mathrm{BM} \downarrow)$ Date of order $+\mathrm{IEAC}_{\mathrm{t}, \mathrm{j}, \mathrm{k}}$ | 22/6/12 | 28/12/12 | 2/08/12 | 13/07/12 | 22/06/12 |
| Forecast Delivery Date, using Long Form equ $I E A C_{t, i, j, k}(B M)$ Date of order $+\mathrm{IEAC}_{\mathrm{t}, \mathrm{i}, \mathrm{j}}$ | 22/06/12 | 28/12/12 | 2/08/12 | 18/07/12 | 22/06/12 |
| Forecast Delivery Date, using Long Form equ $I E A C_{t, n, i, j, k}(B M \uparrow)$ Date of order + $\mathrm{IEAC}_{\mathrm{t}, \mathrm{h}, \mathrm{i}, \mathrm{k}, \mathrm{k}}$ | 22/06/12 | 28/12/12 | 2/08/12 | 18/07/12 | 22/06/12 |
| Forecast Delivery Date, using Long Form equ $\mathrm{EEAC}_{\mathrm{t}, \mathrm{g}, \mathrm{h}, \mathrm{i}, \mathrm{j}, \mathrm{k}}(\mathrm{BM} \uparrow \uparrow)$ Date of order + IEAC $\mathrm{t}_{\mathrm{t}, \mathrm{g}, \mathrm{h}, \mathrm{j}, \mathrm{k}}$ | 22/06/12 | 28/12/12 | 2/08/12 | 18/07/12 | 22/06/12 |
| Forecast Delivery Date, using Long Form equ IEAC $\mathrm{E}_{\mathrm{t}, \mathrm{P}}$ Date of order $+\mathrm{IEAC}_{\mathrm{t}, \mathrm{IP}}$ | 22/06/12 | 21/01/13 | 1/08/12 | 21/07/12 | 22/06/12 |
| Forecast Delivery Date, using Long Form equ IEAC $\mathrm{I}_{\mathrm{t}, \mathrm{F}}$ Date of order + $\mathrm{IEAC}_{\mathrm{t}, \mathrm{IF}}$ | 22/06/12 | 3/08/12 | 15/07/12 | 12/07/12 | 22/06/12 |
| Forecast Delivery Date, using Long Form equ IEAC $\mathrm{I}_{\mathrm{t}, \mathrm{FwCPI}}$ Date of order $+\mathrm{IEAC}_{\mathrm{t}, \mathrm{Fw}}$ WPI | 22/06/12 | 3/08/12 | 15/07/12 | 12/07/12 | 22/06/12 |
| Forecast Delivery Date, using Long Form equ $\mathrm{IEAC}_{\mathrm{t}, \mathrm{IFb}}$ Date of order $+\mathrm{IEAC}_{\mathrm{t}, \text { Ifb }}$ | 22/06/12 | 5/09/12 | 15/07/12 | 12/07/12 | 22/06/12 |
| Forecast Delivery Date, using Long Form equ IEAC ${ }_{t, I F w S P I t}$ Date of order $+\mathrm{IEAC}_{\mathrm{t}, \mathrm{IFwSPIt}}$ | 22/06/12 | 29/10/12 | 15/07/12 | 12/07/12 | 22/06/12 |
| Forecast Delivery Date, using Long Form equ IEAC $\mathrm{t}_{\mathrm{t}, \mathrm{FwSPI}}$ Date of order $+\mid E A C_{t, I F w S P I}$ | 22/06/12 | 29/10/12 | 11/07/12 | 9/07/12 | 22/06/12 |
| Forecast Delivery Date, using Long Form equ IEAC $\mathrm{t}_{\mathrm{t}, \mathrm{IFwSPI-PMIt}}$ Date of order $+\mathrm{IEAC}_{\text {t,IFwSPI-PMIt }}$ | 22/06/12 | 25/09/12 | 24/08/12 | 23/07/12 | 22/06/12 |
| Reporting Date | 23/02/12 | 15/03/12 | 12/04/12 | 10/05/12 | 31/05/12 |

(The remaining 'observational ratio' calculations have been excluded as they represent the same data in different forms)

## C. Appendix C - Photos

C1 Pressure Vessel Configuration Comments
C2 Project T001 - Photos
C3 Project T002 - Photos
C4 Project T003 - Photos
C5 Project T004 - Photos
C6 Project T005 - Photos
C7 Project 'S' - Photos
C7 Vessel Geometry - Photos

## C. 1 Pressure Vessel Configuration Comments

A vessel's configuration has a bearing on schedule topology, horizontal vessels remain more parallel through the fabrication process before having to follow a serial-build pattern. Vertical vessels with legs attached to the cylindrical section of the vessel body also have longer parallel period of fabrication. Vertical vessels with the legs welded to the domed end or those that have a skirt as per Trial T002 have a serial build sequence from the onset. The following images outline a typical vertical vessel for reference:


Prepare Plates


Prepare Domed 'Heads'


Painting


Roll Cylindrical 'Shell'


Assembled and Welding Nozzles


Delivery

## C. 2 Project T001 - Photos

| Photos ${ }^{35}$ | Comments |
| :---: | :---: |
| Preparing Top Heads | Work on top heads is not a critical activity as they are attached to the completed vessel just prior to completion. <br> However they can represent a moderate portion of the labour effort, and therefore need to be completed prior to attachment to avoid the activity becoming critical. |
| Bottom Head Fabrication | Fabrication of the bottom head was a critical and serial activity for this project. |
| Completed Vessel | Vessel completed in black state and ready for testing, prior to painting. |

[^25]
## C. 3 Project T002 - Photos



## C. 4 Project T003 - Photos

Photos ${ }^{36}$ Comments

[^26]
## C. 5 Project T004 - Photos

Comments
The trial assembly stage is a serial
cinch point' in the schedule for both
the vessel and the platforms. (Platforms
are otherwise are non-critical
component).

## C. 6 Project T005 - Photos

| Photos | Comments |
| :---: | :---: |
| Preparing Bottom Head | Vertical vessel with legs welded to bottom head, therefore making this prefabrication work a critical activity. |
| Vessel in Assembled State | Upon completion of assembly of the shell, bottom head and legs (in this case), the vessel can be fitted out with nozzles and other parts. <br> From this point the fabrication has a more serial schedule structure |
| Fitting Nozzles to Shell | Image illustrating the main vessel shell and bottom end assembled and nozzles being fitted. |

## C. 7 Project 'S' - Photos


D. Appendix D - Fortnightly / Monthly CurvesD1 Project T001 - Fortnightly / Monthly Curves
D2 Project T002 - Fortnightly / Monthly Curves
D3 Project T003 - Fortnightly / Monthly Curves
D4 Project T004 - Fortnightly / Monthly Curves
D5 Project T005 - Fortnightly / Monthly Curves
D6 Project S001 - Fortnightly / Monthly Curves
D7 Project S002 - Fortnightly / Monthly Curves
D8 Project S006 - Fortnightly / Monthly Curves

## D. 1 Project T001 - Fortnightly / Monthly Curves




Figure D. 1 - T001 Fortnightly / Monthly EVM and $\mathrm{SV}_{\mathrm{t}}$ Curves (Ref CO-2)



Figure D. 2 - T001 Fortnightly / Monthly IEAC $_{\mathrm{t}}$ Curves (Ref CO-3)



Figure D. 3 - T001 Fortnightly / Monthly EAC Curves (Ref CO-6)

## D. 2 Project T002 - Fortnightly / Monthly Curves




Figure D. 4 - T002 Fortnightly / Monthly EVM and SV $_{t}$ Curves (Ref CO-2)



Figure D. 5 - T002 Fortnightly / Monthly $\mathrm{IEAC}_{\mathrm{t}}$ Curves (Ref CO-3)



Figure D. 6 - T002 Fortnightly / Monthly EAC Curves (Ref CO-6)

## D. 3 Project T003 - Fortnightly / Monthly Curves




Figure D. 7 - T003 Fortnightly / Monthly EVM and SV $_{t}$ Curves (Ref CO-2)



Figure D. 8 - T003 Fortnightly / Monthly IEAC $_{\mathrm{t}}$ Curves (Ref CO-3)



Figure D. 9 - T003 Fortnightly / Monthly EAC Curves (Ref CO-6)

## D. 4 Project T004 - Fortnightly / Monthly Curves




Figure D. 10 - T004 Fortnightly / Monthly EVM and SV ${ }_{\mathrm{t}}$ Curves (Ref CO-2)



Figure D. 11 - T004 Fortnightly / Monthly IEAC $_{t}$ Curves (Ref CO-3)



Figure D. 12 - T004 Fortnightly / Monthly EAC Curves (Ref CO-6)

## D. 5 Project T005 - Fortnightly / Monthly Curves




Figure D. 13 - T005 Fortnightly / Monthly EVM and SV ${ }_{\mathrm{t}}$ Curves (Ref CO-2)



Figure D. 14 - T005 Fortnightly / Monthly IEAC $_{t}$ Curves (Ref CO-3)



Figure D. 15 - T005 Fortnightly / Monthly EAC Curves (Ref CO-6)

## D. 6 Project S001 - Fortnightly / Monthly Curves




Figure D. 16 - S001 Fortnightly / Monthly EVM and SV ${ }_{\mathrm{t}}$ Curves (Ref CO-2)


Project $\mathbf{S 0 0 1}$


Figure D. 17 - S001 Fortnightly / Monthly IEAC $_{\mathrm{t}}$ Curves (Ref CO-3)



Figure D. 18 - S001 Fortnightly / Monthly EAC Curves (Ref CO-6)

## D. 7 Project S002 - Fortnightly / Monthly Curves




Figure D. 19 - S002 Fortnightly / Monthly EVM and SV ${ }_{\mathrm{t}}$ Curves (Ref CO-2)


Project $\mathbf{S 0 0 2}$
Monthly IEAC Usit $_{\mathrm{t}}$ Forecast of Actual Duration ( $\mathrm{AD}_{\mathrm{R}}$ ) Using Earned Schedule Methods


Figure D. 20 - S002 Fortnightly / Monthly IEAC $_{t}$ Curves (Ref CO-3)



Figure D. 21 - S002 Fortnightly / Monthly EAC Curves (Ref CO-6)

## D. 8 Project S006 - Fortnightly / Monthly Curves




Figure D. 22 - S006 Fortnightly / Monthly EVM and SV ${ }_{\mathrm{t}}$ Curves (Ref CO-2)



Figure D. 23 - S006 Fortnightly / Monthly IEAC $_{t}$ Curves (Ref CO-3)



Figure D. 24 - S006 Fortnightly / Monthly EAC Curves (Ref CO-6)

## END OF DOCUMENT


[^0]:    1 Within the context of the host organisation (LAP) small projects are those with a value of less than $\$ 100 \mathrm{~K}$ or 20 week duration, anything over these values is considered as large for this research.

[^1]:    2 This terminology was initially encountered during attendance of the 2011 PMI Global Congress in Dallas TX, USA.

[^2]:    3 The critical ratio can be any number that alters the SAC, however it is frequently based on CPI x SPI.

[^3]:    4 Lipke has developed a calculator for this 'special case' and it is available through www.earnedschedule.com.

[^4]:    5 All page reference within these indented paragraphs are cited from Williams 2003.

[^5]:    6 Representing certain project behaviour based the initial (planned) inputs, as used by Williams.
    Implying the effect of random events from the external project environment, as used by Williams.
    8 This term is presented in 'Williams 2003' p.13, but coined by Williams in a 1992 publication as referenced in the associated text relevant to this discussion.

[^6]:    9 The concept embedded in the Williams citation has been drawn from - Simon, H.A. 1982 Science of the Artificial, Second edn, MIT Press, Cambridge Mass USA.
    ${ }^{10}$ Original source noted as: Rethinking the new project management framework: new epistemology, new insights. PMI Research Conference Proceedings, Seattle 2002 pp.371-380.

[^7]:    11 There are numerous references to work by 'Christensen' covering cost related performance through much of the literature reviewed, however details of this work are considered outside the scope of this research and therefore not referenced specifically.

[^8]:    12 Any time unit may be substituted for days.

[^9]:    13 Decisions may also be influenced by external factors such as changes to 'the business climate'.

[^10]:    14 Refer to Appendix C, part C. 2 for details and photos of project T001. All other projects noted in this and subsequent section are also support by notes and photographs in Appendix C.
    15 The revised $2^{\text {nd }}$ Edition (2011) of this standard does not appear to have the details from the $20051^{\text {st }}$ Edition "Box 1-1: Scaling EVM to Fit Varying Situations" p. 4 included.

[^11]:    16 It is noted that this version of the standard was superseded by the second edition in October 2011. Although this later version was used as a reference the original spread sheet calculations were retained due to their extensive inclusion in research development by this time.

[^12]:    ${ }^{17}$ The PB term is taken from AS4817, however in reference to the PMI Practice Standard for EVM Second Edition (2011, p. 147) the term 'Project Budget Base' (PBB) is analogous to the PB definition.

[^13]:    ${ }^{18}$ Refer to Table 4.1 for details of BAC Groups.

[^14]:    19 The BAC values here reflect labour budget only and sub-contracted scope, such as painting.

[^15]:    20 All equation references are taken from Table 4.6 unless noted otherwise.

[^16]:    ${ }^{21}$ The concept of the 'Dashboard' was communicated in an email from Vizzuett to Fox [14 ${ }^{\text {th }}$ June 2011] during general discussions in applying ES to the supply of pressure equipment.

[^17]:    22 The Project Hours term suits the host organisation; however for research purposes this data is more usefully viewed as a labour profile, where analysis can be made against effort and actual over run.

[^18]:    23 Main cluster implies all but one or two methods have come together when plotted.
    ${ }^{24}$ Weighting assessment was considered by reviewing both the IEAC $\#_{\#}$ and EAC plots to determine date best overall index weighting to be applied.

[^19]:    5 Due to the 10 week duration of this project the weekly frequency values have been used
    6 Project completion was 'crashed' to meet delivery.
    27 Project completion was 'crashed' to meet delivery.
    28 External factors delayed the project.
    ${ }^{9}$ Recalling this measure is a $\%$ of the Planned Duration, therefore value can be $>100 \%$.

[^20]:    ${ }^{30}$ In regard to the seven repeated projects only three (S001, S002 \& S006) were subject to a documented observational review. The remaining results were summarised in Table 5.10 p. 182.

[^21]:    31 Text in Italics represents activities or outputs that posed difficulties in EVM application, the remaining comments reflect aspects that connected well with the organisation and achieved sound improvements at the conclusion of the research window.

[^22]:    32 Through many publications as referenced in this thesis.

[^23]:    33 With respect to the US and use on government related contracts.

[^24]:    34 These phases can be grouped as 'EVM implementation', which is a term that exists in literature relating to the same subject. Recalling Kim et al. 2003.

[^25]:    ${ }^{35}$ The images from C. 1 are also from project T001

[^26]:    ${ }^{36}$ Project T003 was identical to T001, but for one vessel only

