The Impact of a Collaborative Planning Approach on Engineering Construction Performance

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An abridged Thesis submitted in partial

fulfilment of the requirements of Nottingham

Trent University for the degree of Doctor of

Philosophy

August 2017

ACKNOWLEDGEMENT

Completion of this thesis was made possible by the help, advice, guidance and encouragement of many people in the last four years.

I would like to thank my academic supervisors – Christine Pasquire, Roy Stratton, Andrew Knight and UWA academic advisor David Day, for their contribution to the research and help above and beyond what could be reasonably expected. Also, my industrial supervisor Neil Maxfield for his kindness, patience, mentoring and the demonstration of what true transformation leadership looks like, my KGP mentor Mike Watson, for his help, wit and wisdom. Also to some of the true "heroes" of the lean implementation process, Ropes, Paris, Dobbie, Robbo, George and Simon for their good humour and generosity, whose tall tales must be true, for who could make those stories up.

Finally, I wish to dedicate this thesis to my wife and love of my life Annamaria. I could not have started, never mind finished this journey without you.

ABSTRACT

The thesis presents the findings from the longitudinal implementation of lean construction on the ongoing refurbishment of an integrated liquefied natural gas (LNG) plant in North Western Australia. Refurbishment of existing plant is a sub-sector of the Engineering Construction (EC) industry, an industry involved in the design and construction of large-scale industrial facilities including oil and gas plants. The sector is called engineering construction in the United Kingdom and Australia and industrial construction in the United States and Canada. EC is beset with poor performance levels in terms of cost, time and quality outcomes. Despite the ongoing use of innovative practice, the sponsor company experienced similar optimisation challenges in the process of executing construction projects. The research problem was the performance achieved on the ongoing refurbishment projects. The research aim was to investigate the impact a collaborative planning approach on performance and develop implementation guidance.

A quantitative analysis of data from the Sponsor Company (SC) documentation revealed wastes specific to EC refurbishment projects, including transportation and movement, with attendant planning issues. Lean construction uses a collaborative planning approach to act against waste, particularly transportation and movement. Therefore, lean construction was viewed as an appropriate approach to act as an antidote. Observational research was used to address a gap in literature which is the lack of research investigating EC culture and environment. Action research (AR) over 7 cycles, was used to investigate the implementation of elements of the Last Planner® System (LP®S), a collaborative production planning approach, and a collaborative knowledge transfer tool called Team Work Design (TWD), designed and applied by the researcher. Primary data for analysis was extracted from LPS reporting and semi-structured interviews, with secondary data obtained from SC documentation. The longitudinal field research informed the development of implementation guidance. This addressed a gap in knowledge, which is the shortage of such guidance.

The study contributed to research practice and to knowledge. Contributions to practice included the development of guidance for the implementation of the LPS, the development of the TWD tool and the use of pull planning workshops to develop the work strategy and master programmes. Contribution to knowledge included the demonstration of workforce ability to autonomously evolve lean construction practice in response to the work environment. The implication of the research is that the guidance will inform future LPS and TWD implementation.

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LIST OF ABBREVIATIONS

ALARP	As Low as Reasonably Practicable
AR	Action Research
BOK	Body of Knowledge
CPM	Critical Path Method
CI	Continuous Improvement
CUI	Corrosion Under Insulation
DH	Daily Huddle
EC	Engineering Construction
EPCM	Engineering Procurement Construction Management
EVM	Earned Value Method
FEED	Front End Engineering Design
FIFO	Fly in Fly Out
FLNG	Floating Liquefied Natural Gas
FPSO	Floating, Production, Storage and Offload
FRS	First Run Study
IC	Implementation Contractor
IA	Issuing Authority
ISSOW	Integrated Safe System of Work
JIT	Just in Time
KGP	Karratha Gas Plant
KLE	Karratha Life Extension
KM	Knowledge Management
LH	Leading Hand
LI	Lean Implementation
LOC	Loss of Containment
LP	Last Planner
LPS	Last Planner System
LNG	Liquefied Natural Gas
MBM	Management by Means

MBR	Management by Results
MHR	Minor Hazard Report
NVA	Non-Value Adding
OM	Operational Management
PA	Performing Authority
PE	Project Engineer
PERT	Programme Evaluation and Review Technique
PI	Productivity Improvement
PM	Project Management
PMBOK	Project Management Body of Knowledge
PMI	Project Management Institute
PMI	Project Management Index
PTW	Permit to Work
PVI	Project Variation Information
R&R	Rest and Recreation
RDO	Rest Day Off
SIC	Short Interval Control
STIPS	Shutdown Targeted Inspection Points
TPS	Toyota Production System
TFV	Transformation, Value, Flow
VA	Value Adding
WBS	Work Breakdown Structure
SC	Sponsor company
EPCM	EPCM contractor
TWD	Team Work Design
WWP	Weekly Work Plan

1 INTRODUCTION

The research involved the investigation of a lean construction approach on the ongoing refurbishment of a liquefied natural gas (LNG) plant. Engineering Construction (EC), a sector of the construction industry, delivers large-scale industrial facilities, with refurbishment of existing plant forming a sub-sector of EC. The term EC is not universal. Whilst used in the UK (Brookes 2012) and in Australia (Lyons and Skitmore 2004) the sector is referred to as industrial construction in Canada (Fayek, et al. 2006) and in the US (Georgy, et al., 2005). The sector includes a range of projects from oil and gas facilities, power generation plant, large scale manufacturing facilities and large-scale windfarms, most with a value exceeding $0.5 billion dollars (Brookes 2012). Research has identified a common array of issues and problems. These include poor performance levels where up to 75% of the day can be spent on non- productive work (Gibson 2009), and a propensity to cost over-runs and poor-quality outcomes (Georgy, et al., 2005). A literature review demonstrates similar challenges experienced in oil and gas refurbishment, (Brown 2013). The research was sponsored by the SC who wished to investigate performance achieved on the ongoing refurbishment at the Karratha Gas Plant (KGP) in the Australian North West and identify potential improvement opportunities.

1.1 The Research Problem and Background

The research problem was the performance issues experienced on refurbishment of the Karratha Gas Plant (KGP). The research was undertaken over an 18-month period on the ongoing refurbishment of an integrated liquefied natural gas (LNG) plant. This is the KGP located in the Pilbara region of North West Australia. The sponsor company (SC), facilitated the research.

The primary research was carried out at the KGP (figures 1:1, 1:2), owned by Woodside Energy Ltd (WEL), BHP Billiton Petroleum (North West Shelf) Pty Ltd, Shell Development Australia Pty Ltd, Chevron Australia Pty Ltd, BP Developments Australia Pty Ltd, Japan Australia LNG Pty Ltd (MIMI), with WEL as the plant operator. The plant was nearing the end of its design life and is currently undergoing refurbishment to extend its working life. The facility itself is one of the largest integrated liquefied natural gas (LNG) plants in the world. The plant is the onshore component of a system which exploits upstream offshore raw gas, pumped through a pipeline from the remote coast of Western Australia to produce condensate and LNG on the onshore KGP. The raw gas, mainly consisting of methane is treated to remove contaminants, including carbon dioxide, water and mercury and then cryogenically treated to liquefy the gas at a temperature of -164ºC. The plant commenced operation in 1984 with several processing units called trains. The Domgas 1 and 2 trains produce LNG for the domestic market, sent down a 1700km long pipeline to supply domestic and industrial consumption in the Perth metropolitan region. The Domgas trains were the first constructed, followed by LNG trains 1,2,3,4 and 5. Trains 1 to 4 were constructed insitu, a construction process commonly referred to as stick built. Train 5 was modular construction where individual modules were constructed in South East Asian fabrication yards, to be shipped for onsite construction.

Deterioration over time of the protective cladding, insulation and paint systems had resulted in local external corrosion of pipe-work and vessels, requiring corrective maintenance. The refurbishment work is being implemented over a five to ten-year period, extends the operating life of the plant. This work consists of approximately 350 discrete projects, including the corrosion refurbishment described, but also refurbishment of the jetties, removal of redundant plant, replacement and refurbishment of rotating equipment and control systems. Work is carried out on a live plant, with projects undertaken online (on live plant) and offline (on isolated sections of plant), requiring the experience of operators and a workforce who understand the workings and vagaries of a multifaceted and aging facility.

Figure 1:1- Overview of the Karratha Gas Plant (KGP)

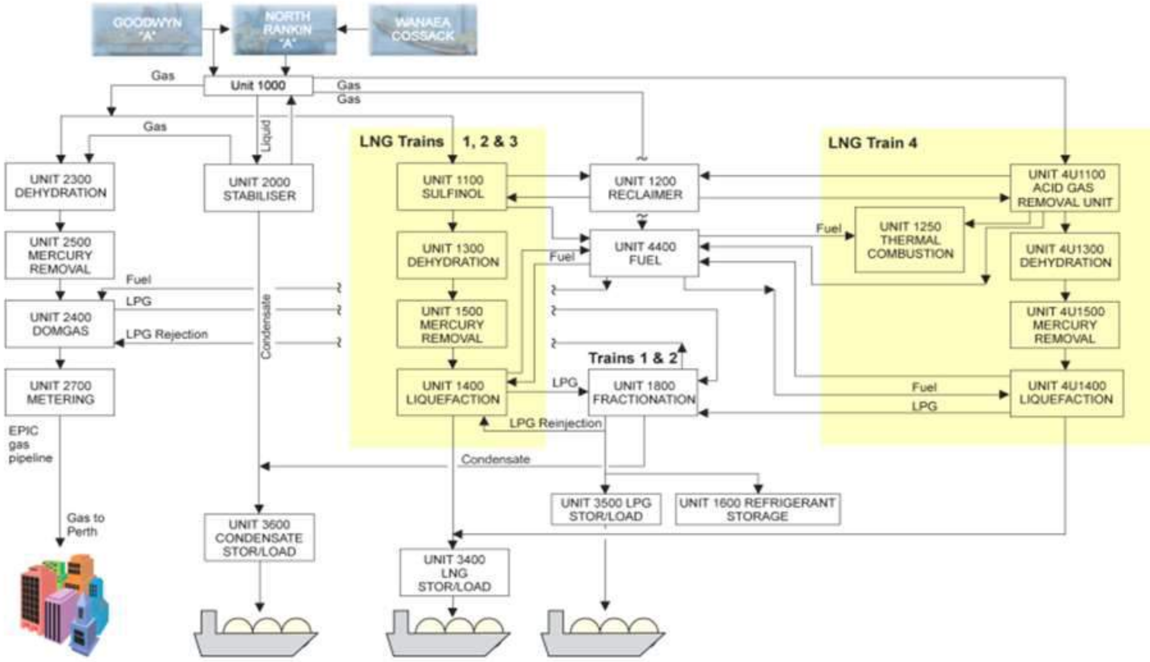

Figure 1:2- KGP Onshore complex

1.2 The Rationale

Over time the sponsor company (SC) has implemented approaches to improve the performance outcomes achieved on its construction projects. These have consisted of workforce centric programmes including the use of lean construction to enhance performance during the final stages of the Pluto LNG project completed in 2010, adjacent to the KGP. Other initiatives comprise consultant led workforce productivity improvement initiatives; ongoing at KGP prior to and during the research implementation. Technology centric initiatives, including the use of modular construction on the original plant construction have been used. This technology was originally developed in the off-shore oil industry to reduce the amount of insitu fabrication required and applied offshore since the mid-1980s, aided by development in craneage and transportation technologies (Brookfield and Cooke 2011). The use of this approach in onshore LNG plant construction is relatively new, first pioneered on the expansion of the KGP train 5 construction. The project was completed in 2008 where the front-end engineering design (FEED) enabled the offsite pre-assembly of modules, for incorporation in an onsite assembly process. Modules were built in a fabrication yard located in Batam, Indonesia and transported in 17 shipments. Costs of modular units are generally 10 - 15% greater than onsite fabrication, but this front-end cost is offset by the schedule, budget reductions and quality improvements gained (Habibullah et al., 2009). These modules vary from tens of tonnes to thousands of tonnes.

However, this large scale technological innovative practice is not suitable for refurbishment projects. The SC recognised that the research had the potential to support improved performance. The researcher has worked mainly as a construction project manager for 30 years in the UK and used a lean construction approach for 10 years. Following an expression of interest, research commenced in 2013 after necessary contractual terms had been agreed and relevant approvals obtained.

The research investigated the implementation of elements of the Last Planner System (LPS) along with a tool developed by the researcher called Team Work Design (TWD), which assists teams in the development and use of continuously improved standard work. The LPS is a collaborative production approach, where Last Planners (LPs) or decision makers use their human potential in knowledge and experience to plan work activities before going live. The approach uses milestones from traditional critical path method (CPM) scheduling to set targets where the LPS exemplar uses phase planning informing weekly production planning (WWP) assisted by a MakeReady process. Metrics collated from the WWP contribute to learning assisting continuous improvement Ballard et al., (2016). However, barriers presented during the research from issues with available CPM schedules produced, militated against the use of the Make ready process, with the outcome that the exemplar was not implemented in its totality. It must be noted that the LPS referred to in the thesis lacks the exemplar MakeReady process.

The following aim and objectives were established in response to the research problem, that is the desire to improve performance on the refurbishment of the KGP.

1.3 Aim and Objectives

The rationale describes the reasons for the research and approaches used. The research aim *was to determine the impact of a collaborative planning approach on performance in engineering construction (EC) and to develop implementation guidance.*

To achieve this, aim the following objectives were set.

- **Objective 1:** To investigate the implementation of the Critical Path Method (CPM) of project planning in Engineering Construction (EC) projects.
- **Objective 2:** To reveal the culture and environment of an EC workforce to understand its impact on performance.
- **Objective 3:** To reveal the current factors that affect productivity in EC projects and to verify the implementation of a collaborative planning approach in EC.

- **Objective 4:** To develop Last Planner System (LPS) implementation guidance, including any necessary supporting approaches.

The research methods used to develop the objectives are detailed in table 1:1 below.

Research Methods			Research Objectives			
			1	2	3	4
Data Collection methods		Literature Review	X	X	X	X
		Observation	X	X	X	X
		Secondary Data collection		X	X	X
		Primary Data collection	X	X	X	X
		Action Research				X
	Interview	Informal Interview	X	X	X	X
		Semi structured Interview	X			
Data analysis		Quantitative Graphing	X	X	X	X
		Qualitative NVivo Coding	X			

Table 1:1-Research Methods assigned to achieve the research objectives

1.4 Outline of Research Design and Methods

A literature review (chapter 2) investigated the existing body of knowledge in relation to three domains, including firstly, engineering construction, secondly, lean construction, its development from flow production and its relationship to traditional construction and finally people potential, particularly social and human capital. The use of lean construction in the EC industry was identified as an under researched area. The research was mixed-methods, using quantitative and qualitative data for analysis. Quantitative data was extracted from SC documentation, time and motion studies and LPS metrics. Qualitative data for analysis came from the action research (AR) cycles and semi-structured interviews, investigating the implementation of the Critical Path Method (CPM), used to schedule construction projects. The AR investigated the implementation over 7 cycles on discrete refurbishment projects, of elements of the Last Planner System (LPS) and a tool referred to as Team Work Design (TWD). The LPS MakeReady element was not implemented due to issues encountered in obtaining robust milestone from critical path method (CPM) planning in use on the refurbishment projects. The AR used iterative research cycles to continuously investigate, learn from and then implement findings from previous cycles in subsequent ones.

The data collected was analysed using quantitative and qualitative analysis as appropriate. Coding was used to manually extract themes for analysis from the AR cycle outcomes. NVivo software was employed to carry out thematic coding of the semi-structured interviews investigating the use of CPM for project planning. Quantitative analysis in the form of graphing obtained information from primary source data collected from the implementation of the Weekly Work Plan (WWP) meetings, time and motion studies and from SC secondary data on productivity and CPM outputs.

1.5 Overview of Work Done

Firstly, secondary quantitative data was analysed. Documentation included lessons learned workshops findings, time and motion studies and project variation information (PVI) collected from a previous 9-month refurbishment at the plant. The analysis demonstrated that there were opportunities to improve performance levels within projects including that of transportation and movement. The most significant delay, was caused by cyclones, followed by planning issues of the refurbishment projects, offering opportunity to improve performance. The most important element of lean construction is waste reduction (Green 1999, Ballard and Howell 2003, Jorgensen and Emmitt 2008, Mao and Zhang 2008, Eriksson 2010), with efficient storage and transportation of parts and materials, called just-in time (JIT), crucial to reduction of waste (Eriksson 2010, Fearne and Fowler 2006). The quantitative analysis revealed lean identified wastes including transportation, movement and waiting in the execution of refurbishment projects at the KGP. Furthermore, all issues revealed, from “schedule overrun” to “materials unavailable” are ones that can be allayed by the Last Planner System (LPS), where teams collaborate to develop production planning, with activities only committed to when constraints such as workforce access, equipment and materials unavailability are removed (Ballard and Tommelein 2016, Ballard 2000). The LPS is now widely used from remote areas in Africa to complex projects in the United States on projects as diverse as housing schemes to engineering construction projects (Howell et al., 2011), but there is sparse evidence of its use on Australian EC projects. The findings confirmed the LPS as appropriate to counter the issues uncovered.

The Action Research (AR) investigated the outcomes from the use of elements of the LPS incorporating TWD over 7 cycles. This is a lean construction approach. Lean construction owes its origins to flow production (Koskela 1993). It identifies and eliminates waste, improving the reliability of work flow (Ballard 2000), meeting customers' requirements whilst pursuing continuous improvement (Diekmann, et al., 2004). The customer may be the client and end user but may also be the team to whom workscope is handed. The LPS includes several components. Firstly, milestones are set, normally from a CPM master schedule. Secondly, phase planning utilises decision makers including principle and sub-contract project managers, project engineers, superintendents and supervisors, collaborate using a pull planning approach, agreeing handovers and work sequence. This planning is typically for 3 to 4 months into the future. This can also be referred to as pull planning. In contrast to CPM, planning starts from the final activity, working back to the first activity. These first two phases plan work that "SHOULD" be done. Thirdly, last planners collaborate using the "MakeReady" tool, assessing and making work ready that "CAN" be done. Fourthly, the Weekly Work Plan (WWP) involves the last planners, including supervisors, superintendents and managers. This normally takes ½ to 1 hour. Here, the last planners commit to the work that "WILL" be done in the upcoming week. The production management phase records completions and reasons for late completion with real time data extracted in the form of percentage plan complete (PPC) metrics. Finally, the learning phase examines non-completion of activities, aiding continuous learning and improvement. The MakeReady phase was omitted because of issues experienced in getting realistic data from the CPM schedules. Furthermore, a pre-shift Daily Huddle (DH) was used. This is a 5 to 10-minute forum where supervisors review the previous day's work. They commit to activities for the upcoming day, exchange information with offers to assist and help.

Team Work Design (TWD) supported the LPS elements and was developed by the researcher in response to gaps in literature. Seddon (2003) notes that those doing work are in the best position to develop standard process to undertake that work. Yet, there is a paucity of research describing workforce input in the development of standard work. Therefore, the researcher developed a tool called TWD where teams doing work, would design the work using first run studies (FRS) in plan, do, check, act (PDCA) iterative cycles. This process assists the development of high performing teams from existing ones, by aiding the development of the 8th flow of common understanding between team members (Hackett, et al., 2015).

The culture and environment was investigated using observation over the course of the research, where findings were used to inform implementation of the lean approach. The culture is predominantly a clan culture which values loyalty where teams participate together with success determined by the value provided to the customer. (Cameron and Quinn (2011).

1.6 Research Findings

An overview of the research objectives issues and findings are detailed in table 1.2. The table lists the 4 objectives, the gaps in literature the objectives address, the relevant parts of the thesis, the research methods used and the findings obtained.

Research Objectives	Gaps in Literature addressed	Relevant parts of Thesis	Research Methods	Findings
Objective 1: To investigate the implementation of the Critical Path Method (CPM) of project planning in EC projects.	Building on literature investigated CPM planning issues. Lack of literature on use of CPM in EC.	Chapter 2 Chapter 4	Literature review Semi- structured interviews	**F1:** The thesis confirmed shortcomings with the use of a CPM software tool. The thesis provides guidance to allay some of the issues identified. **F2:** The thesis developed a novel approach to master programme development where decision makers developed templates and work strategy using pull planning, incorporated into a CPM plan.
Objective 2: To reveal the culture and environment of an EC workforce to understand its' impact on performance	Demonstration of a shortage of research into EC workforce culture.	Chapter 2 Chapter 5	Literature Review Observation	**F3:** The thesis provided information on workforce capabilities. Despite current preconceptions, the workforce has the capability to match the globally best.in productivity achieved. The major reason for poor project outcomes is the shortage of management with experience in large-scale projects. **F4:** The thesis provided an insight into the workforce culture, identified as a "clan" culture
Objective 3: To reveal the current factors that affect performance in EC projects and to verify the implementation of a collaborative planning approach in EC.	Gap in research on EC performance	Chapter 2 Chapter 5	Literature Review Action Research	**F5:** The thesis analysed secondary data to provide evidence that the sector is prone to the potential wastes witnessed in construction in general including waiting, transport and movement waste, with planning issues as one of the major factors affecting performance.
Objective 4: To develop LPS implementation guidance, including any necessary supporting approaches	Little evidence of longitudinal research on the implementation of lean construction on construction projects in general. Lack of literature investigating operationalisation of the 8th flow, common understanding. Lack of literature on the development of higher performing teams from existing.	Chapter 2 Chapter 5	Literature review Action Research	**F6:** The thesis developed guidance to implement LPS in EC refurbishment (table 4:13) **F7:** The thesis developed a tool referred to as Team Work Design (TWD). This aid the development of higher performing teams from existing ones and the transfer of knowledge to facilitate the 8th flow, common understanding.

Table 1:2-Research objectives and findings

1.7 Organisation of the Thesis

The thesis has been divided into six chapters. The main elements of the chapters are described below.

Chapter 1 introduces the study, the rationale for the research, a description of the case study company and a description of the process undertaken at the Karratha Gas Plant (KGP). The research design, data collection methods and analysis were also described. Finally, the contributions of the thesis as they related to the objectives were outlined in table 1.2.

Chapter 2 reviews relevant literature to reveal gaps in knowledge about lean and its implementation. The areas reviewed included traditional construction practice and the general issues experienced. This was followed by a review of construction performance followed by an investigation of engineering construction and performance issues experienced. Flow production was then examined, particularly some misconceptions about its origins, which informed the research implementation. People potential, which included human and social capital, was investigated to examine gaps in lean literature regarding its use. Finally, lean construction was investigated along with an investigation of other domains, uncovering existing practice to aid the implementation of lean construction.

Chapter 3 presents the methodology and research design. It describes the methods available and those chosen for the research. It describes the method used during the primary research, which was action research. It describes the limitations and the demonstration of rigour to mitigate against the limitations inherent to the research method used.

Chapter 4 describes the initial research used to gain an understanding of the environment that the research was to be carried out in, the performance barriers and to determine if lean construction offered a potential antidote. It presents the findings on the interaction of Critical Path Method (CPM) and the Last Planner System (LPS) and the issues revealed from the use of the CPM.

Chapter 5 reports on the implementation of the LPS in seven distinct cycles, the lessons learned from each cycle and how these informed the implementation of the subsequent cycle. LPS integrating with Team Work Design (TWD) was implemented on discrete refurbishment projects with lessons learned collaboratively on each cycle informing implementation of the subsequent cycle.

Chapter 6 presents the analysis, conclusions and findings.

Conclusion

This chapter has outlined the research. Engineering construction (EC) is the sector involved in the construction of large-scale industrial projects. This sector is referred to as engineering construction in the UK and Australia and industrial construction in the US and Canada, experiencing the same issues as the rest of the construction industry, with poor performance levels experienced, where most projects are completed behind schedule and budget. The sub-sector investigated was the refurbishment sector, in this case the refurbishment of a liquefied natural gas (LNG) plant. The primary research was undertaken on the ongoing refurbishment of an integrated LNG plant in North West Australia. After identifying the research need, the chapter has presented the research problem. It has also presented the research design. The literature review revealed gaps in knowledge. It has also provided an overview of the research methods used and the contributions to knowledge.

2 Literature Review

Fellows and Liu (2008) stress the importance of a critical review of previous literature to demonstrate an appreciation and understanding of the state of knowledge of the topic and its context. Likewise, Farrell (2011) says that the review should bring together common literature themes, to make intelligent links and demonstrate that the literature has been examined with insight. The literature review reflects the research aim and objectives with several literature sources reviewed. These included, academic books and peer reviewed journals including; Journal of Management within Engineering, International Journal of Project Management, Project Management Journal, Construction Management, Journal of Construction Engineering and Economics, and Economics and Organisational Science. Literature was also reviewed from papers published by the International Group for Lean Construction (IGLC). This literature source is open to criticism in that whilst this is peer reviewed, it is normally only reviewed within the lean community. However, lean literature, peer reviewed by a wider community was also used. Literature also included industry reports and consultant's reports. Whilst industry reports are not peer reviewed, they are one of the few data and information sources available on the engineering construction (EC) industry. Furthermore, consultant reports were used. These used literature review and government statistics, but do not reveal data used to produce their own graphs. Nonetheless, they were used because consultancies, particularly major international ones' influence industry strategy and perception. This is in part due to their employment by the companies involved in EC and their ongoing input into development and implementation of production improvement initiatives.

The following were investigated:

- Traditional construction practice, particularly the current planning approach employed and productivity issues experienced,
- EC and productivity issues experienced,
- Flow production, its origins and evolution to lean construction and
- Culture and its impact on performance.

The next section investigates traditional construction, the planning approach, productivity and other industry issues. Due to the paucity of literature on EC, traditional construction practice literature has been reviewed, to provide a theoretical foundation and to draw inferences for EC.

2.1 Traditional Construction Project Management

The Project Management Institute (PMI), exemplifying the use of the cost and efficiency model, set up in the mid-1970s, initiated the concept of project management as a profession (Hodgson and Cicmil 2007). One of the requirements of a profession is the ability to demonstrate a distinct knowledge base as well as the ability to master and utilise that knowledge. Consequently, with an imperative for some sort of certification to demonstrate that mastery, a pilot baseline attempt was drawn up in 1983 (Morris, et al., 2006). Its aim was to define a project management body of knowledge (BOK). This proposed six knowledge areas, which were scope, time, cost, quality, human resources, and communications. In 1987, the PMI formally published the first edition of the project management body of knowledge (PMBOK), adding risks, contracts and procurement. A 1996 revision added integration as a knowledge area and changed the name to a "Guide to the project management body of knowledge". There have been several upgrades since, mostly minor with Project Stakeholder Management added in 2013 (Morris 2013).

The PMI uses a cost and efficiency approach with current project management demonstrating a lack of explicit theory with any theory discernible is implicit (Koskela and Vrijhoef 2001). Koskela says that implicit theories are difficult to generalise or test, so applying them to new situations proves difficult (Koskela 2000). Discernible theory can be divided into a theory of projects and three theories of management; the thermostatic model of control, management as planning, and the dispatching model of execution (Fernandez and Fernandez 2009, Koskela and Howell 2002). Theory of projects assumes that the successful outcome of a project can be achieved by a transformation or conversion of inputs into outputs. Projects are planned and executed by means of the Critical Path Method (CPM) using work breakdown structures (WBS), decomposing activities into simple sub-activities. It is taken as a given that these activities can be progressed as required with a high degree of certainty. No allowance is made for interrelatedness or variability; assumed away with the construction process seen as a simple transformation or conversion of inputs to outputs (Koskela 2000, Vrijhoef and Koskela 2000). Ballard notes that this mentality is the antithesis of workflow management and:

> *Unfortunately, this approach is the opposite of robust. When something goes wrong, as it very often does, the entire structure is prone to collapse, (Ballard 2000, p.1-1).*

The thermostatic model of control is a feedback control model, which assumes that:

- *There is a standard of performance,*
- *performance is measured at the output (or input) and,*
- *the possible variance between the standard and the measured value is used for control, (Koskela and Howell 2002, p.5).*

This is a management by results (MBR) approach, operationalised by Critical Path method/ Earned Value Method CPM/EVM planning software (Kim and Ballard 2010). Johnson and Brooms (2000) note that MBR is a reductionist cost and efficiency approach. In this, complex interactions are reduced to sub optimised quantitative terms. Predicted performance is baselined in the project plan with data continually gathered to make corrections to this plan. Koskela and Howell (2002) note that the theory of planning assumes that once a plan is formulation by management, it can be implemented by the simple process of issuing orders with no feedback required between the planning and execution phases. The theory of execution assumes that activities can be simply assigned to work groups with planning taken care of by a central authority who notifies the designated work group of the work requirements.

Mir and Pinnington (2014) note that advances in tools and processes have not produced appreciably improved project outcomes. Despite the increasing number of professional bodies, and research undertaken there is little discernible improvement, with cost and time overruns the norm in the construction industry (Gauthier and Ika 2012). This may stem from the deep-rooted approaches to projects and project management in the construction industry where managers are mainly viewed as implementers and the concept of "best practice" assumes rationality of action which:

> *Typically assumes, universality, objectivity, and value-free decision-making, and the possibility of generating law-like prediction (Cicmil and Hodgson 2006, p.111).*

Newell et al., (2009) note that "best practice" is a socio-political process of negotiation rather than an objective reality, the implementation of which leads to "vanilla" solutions, and (Boisot 1998 : p. 47) says that skilled artisans will fiercely resist having their hard won tacit skills reduced and "fossilized" in a process of codification needed to develop "best practice".

The predominant approaches used in undertaking planning and scheduling in construction projects management is the Critical Path Method (CPM); a rational predictive approach. This method is investigated in the following section.

2.1.1 Traditional Scheduling and its origins

The Critical Path Method/ Earned Value Method (CPM/EVM) is a scheduling method operationalizing PMI philosophy. A DuPont engineer, Morgan R Walker and a Remington Rand computer expert James E Kelly initially developed the CPM which involved the use of unique arrow filled diagrams or networks (Archibald and Villoria 1967). At approximately the same time the U.S. Navy initiated a project called PERT (Program Evaluation and Review Technique) to provide naval management with an effective means of periodically evaluating the information of the new Fleet Ballistic Missile program. PERT deals with time constraints only and should be integrated into other planning methods (Weaver 2007). An underlying assumption of the CPM approach, is that projects activities can be broken into sub-tasks which are resourced and given durations, start dates and end dates.

Planning includes plans and schedules. A plan is a high-level document used to deliver and communicate scope, cost and schedule. The schedule is a lower level document normally communicated in the form of a “Gantt chart”, listing milestones, interrelated activities, resources, start and completion dates. The resources can include trades, equipment and other details deemed to be required. Horizontal lines communicate all this with a vertical pane providing activity description, dates and durations. This chart is commonly referred to as a Gantt chart (Stelth and LeRoy 2009).

Galloway (2006) notes that whilst CPM has been in use since the 1950’s it has still not received total acceptance or consistency of use in the construction industry. Noting a gap in literature, Galloway carried out research to address this issue. Using questionnaires to gauge owners and contractor’s views on CPM, she received 430 responses from across the industry in the US. Owners reported several concerns, included a lack of expertise among construction staff on the use of software. This was particularly conspicuous with Primavera®, the dominant software package used in the industry, where its complexity causes the need to employ software specialists as planners. It was also felt that CPM can be easily manipulated for claims purposes. Nonetheless, contractors believed that there was an economic benefit in using CPM, with its use giving a sense of control to the project team, enabling them to plan. However, in general it was noted that the workforce and supervision struggled to make sense of schedules produced.

Literature demonstrates further shortcomings. CPM is ineffective in dealing with multiple constraints such as deadline and resource limits (Hegazy and Menesi 2010), does not allow for the interruption of activities (Shi and Deng 2000), and whilst useful for reporting, is less useful in reflecting the project reality in order to support decision making (Hegazy and Menesi 2010). Furthermore, some research demonstrates misuse of the software to produce illogical impractical schedules (Korman and Daniels 2003). Stelth et al., (2009) notes further advantages and disadvantages in using CPM. Advantages include; it encourages the graphic representation of project activities, enabling teams to plan in a logical manner. It assists in resource allocation during critical path analysis (CPA) and aids the identification of problems particular to critical activities. Some disadvantages identified, include that as CPA becomes more complicated for larger projects, it becomes increasingly difficulty for project teams to understand the interrelated elements of the construction process. In addition, as critical paths change, resource requirements also change, making it difficult to reallocate resources to align with ever changing schedule driven requirements. The very complexity of the software and its reporting is a factor that acts as a barrier to its effective use.

The CPM is a cost and efficiency tool using logical planning to achieve efficient completion of tasks and thence maximise productivity outcomes (Kim and Ballard 2010). The following section investigates productivity and performance within the general construction industry.

2.1.2 Construction Productivity and Performance

There are several definitions for productivity. In construction, productivity is usually taken to mean labour productivity. This is defined as units of output per man-hour input. The inverse definition may be used which is man-hours per unit of output. The productivity capabilities of a construction labour force significantly determine the success of a construction project (Nasirzadeh and Nojedehi 2012). There is a strong correlation between productivity levels achieved, with cost, and time outcomes of projects (Kaming et al., 1998). Productivity can be measured at an industry, firm, or project level with many interrelated factors causing low or reduced productivity. These include change orders, shift work, job satisfaction, organisational commitment, use of technology and innovative practice and site congestion (Nasirzadeh and Nojedehi 2012).

A literature review reveals a shortfall of research into construction productivity. Yet, one researcher; Randolph Thomas stands out, having undertaken detailed research into construction productivity and its measurement, in the process developing benchmarking theories. Some of this research involved the collection and analysis of quantitative data to study the effects of construction changes on labour productivity. Research included the effects of change on productivity where change is defined as any alterations made to the original scope of work (Thomas and Napolitan 1995). The workforce itself collected productivity output data from 522 days of work on three industrial projects. Data collected was the times spent (earned values) completing tasks such as pipework and conduit. This output data, converted into standard outputs using conversion factors was analysed using statistical ANOVA (analysis of variance). The analysis considered several factors that could affect efficiency, including changes, rework, disruptions and weather. The study concluded that on average there was a 30% loss in efficiency when changes occurred, causing disruption due to a lack of materials, a lack of information and out of sequence working.

In further research, Thomas collected data on masonry scope of works of 23 projects, to assess variability and disruption, and so measure how variability levels effects productivity outcomes. The following indices were used, the disruptive index (DI), the Project management index (PMI) and the ripple effect. The DI measures variability by assessing the number of abnormal workday experienced on a project, where an abnormal workday is defined as a day where production hours lost due to disruption exceeds the project norm. The PMI measures the influence of management on a project's cumulative productivity. The ripple effect is a phenomenon describing a highly-disrupted project where the work of a crew is affected daily, often by the work of others (Thomas and Zavrski 1999). Using statistical analysis, Thomas et al, (1999) concluded that projects experiencing high levels of variability, performed less well than those with low variability. Furthermore, high variability was an indicator of poor performing projects.

Another factor, adversely affecting labour efficiency, is deviation from normal workflow due to schedule acceleration. An analysis of electrical scope workflow deviation on three projects, demonstrated that contractors on projects subject to accelerated schedules incurred losses in production of up to 25% (Thomas 2000). This production loss was caused by a reduction in workflow due to large amounts of work being made available coupled with pressure to accelerate schedule. Disruption then occurs, either through overloading following attempts at programme acceleration, or conversely because of an insufficiency of work for available resources. On the other hand, reduced output variability leads to better project performance and costs (Thomas et al., 2002).

The theme that consistently emerges from the research Thomas and others have undertaken is that variability in the production process leads to poor productivity outcomes. Thomas looked for antidotes. He noted the importance assigned to managing variability in the lean construction approach.

He comments on the simplicity of the PPC (percentage plan complete) metric within the Last Planner System (LPS) and the positive correlation of consistently high PPC values with improved productivity. However, he notes that more research is needed to establish the causal vector between PPC levels and productivity outcomes (Thomas et al., 2002).

Other productivity research investigated the use of benchmarking, recognised as a prerequisite to enable tracking, measurement, and then improvements of a process. Nasir et al., (2012) notes that the implementation of a benchmarking program in Canadian construction projects in 2006 demonstrated the benefits of establishing a sustainable benchmarking and metrics program. Companies involved in the data collection and benchmarking program attained superior productivity outcomes to those not involved. However, difficulty experienced in gathering data and information suggested that productivity metrics should be kept as simple as possible. The literature search also reveals further research undertaken on how the implementation of lean construction tools affects productivity outcomes. Abdel-Razek et al., (2007) carried out research on 11 Egyptian projects measuring productivity outcomes following the implementation of two lean construction principles. The two approaches used in these projects were benchmarking and the reduction of variability. Following statistical analysis of the data, it was concluded that the use of these principles contributed to improved productivity outcomes, with daily labour productivity variability having the greatest impact on project performance.

Yet, Eastman and Sacks note the difficulty in measuring construction productivity. This is caused by the wide variety of production activities and project types, with projects ranging from complex petrochemical facilities to highway schemes to houses. All this makes longitudinal research and data collection difficult (Eastman and Sacks 2008).

Several authors discuss an alternative; performance. Performance may be defined in terms of cost, schedule and quality outcomes (Kerzner 2006), or measured in terms of schedule, quality, environmental impact, work environment and innovation outcomes (Eriksson and Westerberg 2011). Several factors determine time and cost performance. Odesola (2015), evaluated the relationship between construction labour productivity and project performance. Using ANOVA analysis of data from 180 public building projects in Nigeria he established a positive correlation between the two. The nature of collaborative or conversely adversarial practice also affects performance. Larson (1995), investigated 280 construction projects, to measure these relationships, categorised as, adversarial (78 projects), guarded adversarial (66), informal (77) and formal partnering (59), with findings that adversarial type projects had the lowest performance levels. Greenwood (2012) investigated the relationship between collaborative practice and construction project performance where collaboration was operationalised in terms of mutual understanding and respect, communication, problem solving mechanisms, sharing of risk/benefits, innovation and creativity. Analysis of data collected through questionnaires from clients and contractors on 44 construction projects in the North East of England confirmed a positive correlation between collaborative working practices and performance in terms of time, cost and quality and client value proposition.

The above confirms the difficulty in assessing construction project productivity. The alternative is the use of performance to measure construction project outcomes. Measures can include time cost quality and innovation outcomes. The next section investigates a sector of the construction industry; engineering construction, and associated performance issues.

2.2 Engineering Construction

2.2.1 The Engineering Construction Industry

Engineering construction (EC), also known as industrial engineering usually involves the construction of large complex projects. However, the term is not universally applied. In the UK Brookes (2012), notes that this sector encompasses oil and gas facilities power generation and large industrial complexes. Lyons and Skitmore (2004) use the term to describe large-scale engineered centric projects in Queensland Australia. In Canada and the US (Georgy, et al. 2005) the sector is referred to as industrial construction. It includes projects such as oil and gas and the tar sands in Alberta Canada. But, the sector is referred to as engineering construction (EC) in the thesis. Sun et al., (2011) states that EC projects tend to have long construction time frames (over two years), long operation lifespans of 50 years or more. They present complex challenges and difficulties in design and construction to project management teams. These projects are complex schemes to design and execute with a tendency to overrun on projected schedule and budgets (Locatellli and Mancini 2012).

Engineering construction differs in several ways from other construction sectors. Firstly, EC projects are made up of a high proportion of mega-projects, where a mega-project is defined as one with a capital cost more than USD500 million (Brookes, 2012). Secondly, there tends to be a low number of end users, with commissioning undertaken by the client, who are normally the owners/operators of the plant. Therefore, stakeholder interactions tend to be less complicated than in other construction spheres. Thirdly, this sector draws a global workforce together with a wide range of disciplines from civil and structural engineering, to control, mechanical, and electrical engineering. Finally, there are complex projects regarding supply chain management, design, collaboration, project management, and constructability (Pasquire 2012).

Pasquire (2012) proposes some differentiating factors between standard construction (building and infrastructure) and EC where the value proposition is to construct and commission a plant that efficiently executes a process, involving some type of transformation through reaction, either thermal, chemical or mechanical, with little human input. These projects require compliance with stringent regulations. Construction is typically of a long duration, frequently undertaken in harsh environments, requiring a highly skilled work force with the construction process utilising a high amount of off-site fabrication. There is a requirement for stringent testing and commissioning to make the plant operational. Once operational, the plant normally consumes a large amount of energy. The process and technologies used are normally copyrighted and commercially sensitive.

On the other hand, the value proposition in standard building and infrastructure construction is to build structures for use either directly or indirectly by people. There is limited use of off-site manufacture and construction is not normally highly complex. However, the structures may include some complexity in IT and mechanical, electrical and plumbing (MEP) systems. The construction phase utilises a narrow range of skill sets with some requirements for specialist trades. Construction is not normally undertaken in harsh environments There is limited need for commissioning, when required it is mainly in the IT and MEP phases. The projects themselves tend to be relatively short term, with building project clients tending to be inexperienced but infrastructure project clients normally more experienced. Most of the technology used is not copyrighted and has commonality across the sector (Pasquire 2012).

However, despite the complexity, importance and cost of EC projects, research in the sector is sparse with Merrow among one of the few researchers' active in the field (Winch 2012). Some of this research included analysis of questionnaires collected from 318 engineering construction megaprojects. Merrow concluded that whilst one-third of engineering construction projects are good the rest are "horrid" (Merrow 2011). These projects turn horrid for several reasons, with "project shaping" being the core one. Project shaping is the process of turning the investment proposal into a clear value proposition, providing a project's line of sight and:

Projects fail for reasons having nothing to do with the shaping but not very often. Shaping errors and omissions are the most common root cause of megaproject failure (Merrow 2011. p103).

The other process in play is project front-end loading. This is an iterative process, converting the business case into a viable project. This has two phases. The first phase is the early design and budget development where enough development needs to be undertaken to ensure project feasibility from a budget and design perspective. The second phase is the detailed front-end engineering development (FEED), followed by the build-up of resourced planning in readiness for the execution phase. The veracity and quality of data and information informing these phases will influence successful project outcomes. The “owner team” role is pivotal, creating value for the owner by directing the development of robust project front-end loading (Merrow 2011).

Fayek et al., (2006) investigated issues of low performance in the EC in the tar sands of Alberta Canada, analysed data from owners and the supply chain questionnaires to determine the correlation between performance and project variables. They concluded that an experienced well qualified project team using good communication is critical to the success of large EC projects. Furthermore, competent supervision and a work force with appropriate skillsets can anticipate impending issues and develop mitigating strategies to minimise negative outcomes in terms of cost, schedule and quality.

Young (2012) in a report on the performance of Australian industrial projects notes ongoing improvement reported on smaller projects ($AU 100 million) over the previous ten years to the point where some projects are now matching the best performances seen global. Yet, this trend has not been matched on larger technically complex projects, which experience 75% failure rates, where failure is defined as cost and schedule overruns of 25% or greater. Projects above $AU 100million experience a high degree of uncertainty, where outcomes become increasingly unpredictable and failure more likely. A report by the Business Council of Australia (BCA) provides some explanations. These include the small number of mid-range projects up to $AU 2 billion constructed within the Australian EC industry (BCA 2013). Consequently, construction professionals have little opportunity to develop experience and expertise in the complex mega-projects arena. Madder et al., (2012) points to a lack of appropriate continuous professional development for EC project management staff, noting a lack of systematic continuous professional development with training being ad hoc and “accidental”. They propose that

EC organisations adopt a more structured approach to appropriate continuous professional development.

EC in common with the construction industry in general suffers with issues of knowledge transfer and learning within and between projects. Project reviews are rarely undertaken and when undertaken usually apportion blame (Love et al., 2005). Gannon and Banham (2011) report on research investigating the challenges of knowledge management on EC projects, offering recommendations for improvements. The authors noted the complex nature of knowledge transfer, yet the process works when structures are in place that aid collaboration and communication between members. Conversely, a lack of a knowledge strategy creates mistrust and frustration which in turn adversely impacts on morale and efficient work practice. Sun et al., (2011) suggest the project management team develop a strategy prior to project commencement. with the aim of promoting unity, good communication and a collaborative culture in project execution.

2.2.2 Engineering Construction Performance

A Price Waterhouse Coopers report on the global oil and gas industry notes that despite advances in technologies and production improvements, global performance from oil and gas facilities has declined by 50% relative to capital employed in real terms in the previous 10 years (Cooke and Capper 2013). This trend is also seen in Australia where the oil and gas industry is criticised for its inability to construct to time and budget. It is clear the industry has ongoing issues with performance. Ellis et al., (2013), report an escalation of costs over the last decade to a point where it now costs 20%-30% more to build in Australia than on comparable projects in North America. Australia's costs are driven both by compressible and incompressible factors. Compressible factors can be addressed. These include existing levels of taxation, regulatory approval times and labour productivity. Incompressible factors are more intractable and include higher ambient air temperatures causing greater inefficiencies than experienced by plant in cooler climes. The relative disadvantage with other gas and oil producing nations on the immovable incompressible factors means that the Australian industry needs to surpass the competition in the areas it can. A report by the Business Council of Australia reported eighteen planned resources projects cancelled or delayed over the previous 12 months, due to inabilities to contain capital costs (BCA 2013). The total capital cost estimate for these projects was $AU149 billion with the WEL Browse LNG project the largest project delayed, at an estimated cost of $AU43 billion.

The report notes that if costs become too high investment will move overseas. However, one incompressible factor that can be targeted, to mitigate against this eventuality is current productivity levels. Nonetheless, considerable improvements, particularly in productivity need to be found. Failure to do so will adversely affect the prosperity of the entire Australian economy (Ellis and Legrand 2013).

Ellis et al., (2013) in an examination of performance shortfalls in LNG plant construction point to some of the following issues:

- *Australian workers spend less time at work because of different shift patterns, to some extent driven by the remote locations of LNG developments,*
- *When at work, time spent working productively is lower due to multiple causes, such as material and equipment not being available,*
- *When working, time is spent less effectively due to relatively less experienced workers, which can lead to rework and*
- *Australian workers take 30 percent more time to complete the same work, as do their counterparts in the US* (Ellis and Legrand, 2014, p. 14).

McCreery and Murphy (2014) and the BCA report (2013) findings broadly align with these performance figures. Using the US Gulf Coast as a benchmark, both declare that on average Australia has a performance factor of 1.35, as compared to 1 on the US Gulf Coast. Simply translated this means that it takes 35% longer to do a piece of work in Australia. The BCA report (2013) agrees in part with Ellis et al., and tease out some constraints to good performance. These include distances travelled between work break areas and the work fronts and logistical issues experienced due to the remoteness of the sites. This report also highlights other issues such as the hot climate, the fly in fly out (FIFO) arrangement, which causes a "drift" to longer working hours. It is noted that whilst peak productivity occurs for 45-50 hrs per week, the longer hours worked under FIFO risks putting people in:

Low energy mode, with resultant lowering of productivity levels (BCA 2013: page 22).

McCreery (2014), notes that the Australia oil and gas workforce is an experienced one, experience gained on the ongoing construction of oil and gas facilities. Nevertheless, the available pool of experienced personnel has been stretched in the past due to the large number of LNG projects under construction in the country. However, a government report indicates an easing of skills shortage, noting that the challenge now for many organisations:

Is to get the people with the right skills in the right place at the right time (AWPA 2013, p.162).

Yet, in contrast to the Ellis et al., (2013) findings, the BCA (2013) report notes that in the main, this "direct" labour force is not the major causal factor of poor performance and indeed direct labour force performance matches the best seen globally. "Indirect" factors such as management, design, procurement and scheduling as well as support services such as scaffolding are a major cause of poor performance. The resultant aggregated performance factor is 1.3, in comparison to the US Gulf Coast (BCA 2013). Therefore, the focus of performance improvements needs to be on the "indirect" element of the aggregated level.

Meanwhile, in the UK, Gibson (2009) carried out a report on engineering construction. The report sought to address two "fundamental questions" in the UK engineering construction industry. The first question addressed whether UK productivity and skills in engineering construction were lagging other industrialised countries and secondly asked what could be done to improve current productivity levels. The report highlighted areas where the UK underperforms in comparison with other countries, noting shortfalls in the following areas:

- *the use of integrated client teams involving construction and operations managers from the beginning of the project;*
- *investing sufficient time in planning and scheduling before construction;*
- *the criteria for contractor selection; the schedule strategy, particularly the amount of design completed when construction begins;*
- *using robust project controls owned by the client;*
- *having sufficient numbers of supervisors;*
- *using local labour (as opposed to men travelling within the UK) and*
- *involving craft labour in construction task planning. (2009, p.18).*

The Gibson report (2009), looked specifically at issues experienced by the British EC industry. This report has been one of the widest ranging to date and one of the few to address the UK sector in totality. The report used evidence collected from many sources. These included an analysis of literature on industry performance, meetings and discussions with global clients and contractors, site visits, dialogue with trade unions and the use of data and analysis produced by Independent Project Analysis Inc. (IPA).

The report notes that whilst the technical skills of the UK workforce may be equal to those in other countries, productivity levels are somewhat lower than those achieved globally. Between 1998 and 2008 for construction and refurbishment of petrochemical facilities, productivity has been 11% less than the US Gulf Coast and 5% less than mainland Europe (Gibson 2009). Furthermore, several British workforce characteristics affect productivity, one of which is aging, with 41% of the onsite workforce over 50 years of age and 65% over 40. The report also proposes further reasons for the variable productivity rates achieved in 2009, which include:

> *Unexpected restrictions caused by the condition of the site which only came to light after construction has started; inadequacies in the design, delays in delivery of equipment to be installed, poor project scheduling or the organisation of the site: low work rates: inadequate supervision and industrial disputes. (Gibson, p.15).*

Consequentially, a lot of unproductive time is expended on projects, where in some extreme cases up to 75% of the working day is spent on non-value adding activities.

The issues of worker productivity are also examined, informed in part by interviews carried out with employers on the subject, who were almost unanimous in questioning craft-worker commitment and loyalty. They state that the workforce has lower than expected work rates, are prone to absenteeism and take longer break periods than allowed. Gibson counters that senior management must accept a large degree of responsibility for this culture described and that the responsibility for the lower productivity experienced in the UK rests ultimately with management. Among other things, management tend to select supervisory staff based on their competencies on the tools rather than man- management skills (Gibson 2009).

These issues described are also encountered in oil and gas refurbishment, an EC sub-sector. This includes low performance levels experienced in Floating, Production, Storage and Offload (FPSO) life extension projects in the North Sea (Brown 2013), delay and cost over runs of oil and gas refurbishment works in Singapore (Wall 2014), scope creep, lack of definition and low efficiencies experienced on oil and gas refurbishment projects (Folkert and Brouwer 2014). Yet, there has only been a small amount of LNG refurbishment undertaken worldwide with the Karratha Life Extension (KLE) the first in Australia to undertake the refurbishment of an LNG plant.

Construction productivity is “difficult” to measure (Eastman and Sacks 2008), but Odesola (2015) notes a correlation between productivity and performance. The EC industry suffers from issues with poor outcomes in performance, measured in terms of times cost and quality and innovative implementation outcomes. This informed the research implementing lean construction where the impact of implementation was measured in terms of performance outcomes. Lean construction is an approach that seeks to improve project performance and owes its origins to lean or flow production (Eriksson and Westerberg 2011).

2.3 Flow production

Holweg (2007) says that the rise of lean production practice not only challenged the established status-quo of the existing batch and queue production model within the automotive industry, shifting the trade-off between productivity and quality, but also lead to the use of lean manufacturing across an array of manufacturing industries. Krafcik who coined the phrase “lean” says that Toyota developed lean production, operationalised by the Toyota Production System (TPS), by workers carrying out a variety of tasks work in teams, enabling them to continuously improve the way they went about the work (Krafcik 1988).

Taiichi Ohno who led the development of TPS in Toyota from the 1950s onwards, relates the story of the implementation in his book (1982). The aim of the book was to provide a narrative on the development of the TPS. Ohno states that the main aim of TPS was the reduction of time between receipts of an order to receipt of payment, achieved by the continuous removal of nonvalue-adding wastes. Ohno built on the work of the founder Sakichi Toyoda, who in 1918 following the invention of an auto activated loom, established the company as a weaving and spinning business. He then sold the patents to the Platt Brothers of England in 1929 for £100,000, instructing his son Kiichiro to use this sum on automobile research. Kiichiro set up in the auto industry initially using Ford and GM components (Cusumano and Nobeoka 1998), developing a production method incorporating the just in time (JIT) concept. The Second World War was a difficult period for the company, with further post war deterioration leading to labour disputes and large inventories of unsold vehicles. Kiichiro resigned in 1950 when the company split into Toyota motor manufacturing and Toyota Motor Sales division. His cousin Eiji Toyoda, now the managing director of the manufacturing arm, was determined to implement mass production techniques, after a trip to the United States in 1950. However, he was thwarted in this endeavour when constrained by the availability of finance and the low volume demands of the Japanese market. Ironically, these constraints aided the development of the TPS, with the establishment of the twin pillars supporting the system, JIT and autonomation:

> *Just in time means that, in process flow, the right parts needed in assembly reach the assembly line at the time they are needed and only in the amount needed.*
>
> *Autonomation means that a worker is not needed while the machine is working normally. Only when the machine stops do it get human attention. As a result, one worker can attend several machines, making it possible to reduce the number of operators and increase productivity efficiency (Ohno 1982: p.8).*

Ohno's mantra was that waste presented the greatest obstacle to an organisation reaching its potential. This waste occurs because people instinctively feel more secure with a large amount of inventory.

Whilst developed by Toyota in the 1950's, it took the publication of the book "The Machine that Changed the World" (Womack, Jones and Roos) in the 1990's to bring the concepts of the TPS and JIT to the attention of a wider western audience. Research for the book was carried out over a period of five years at a cost of $US5 million by an international team of researchers visiting component plants and motor vehicle plants worldwide with an almost evangelical zeal to:

> *tell the story of how human society went from making things during the rise, and now the decline of the age of mass production, and how some companies in some countries have pioneered a new way of making things in the dawning age of lean production… we provide a vision of how the whole world can enter this new age (2003, p.6).*

Womack et al., describe the three main types of production. These include craft production, mass production and lean production. They note that lean production combines the advantages of mass production and craft production, enabling manufacturers to produce a high variety of products with a multiskilled workforce using flexible automated machinery. TPS was rebadged as lean production because it uses half the space, the machinery and the labour and development time than mass production (Womack et al., 1990). Womack et al., agree with Ohno that lean production originated at Toyota as TPS:

Taiichi Ohno soon concluded that mass production could never work in Japan. From this tentative beginning were born what Toyota came to call Toyota Production System and ultimately, lean production (Womack et al., p.48).

Ohno (1982) claims the two pillars needed to support TPS, which are JIT and autonomation as creations of Toyota, saying these were taken from the ideas and practice of Toyoda Sakichi. TPS operationalises the flow approach. Seddon notes that this is a system based approach which:

Represents economies of flow. The system is designed to produce order, so the focus is on flow rather than function. All the information needed to do the work is integrated with the work itself, not in separate systems. The consequence is that variety can now be managed in the same system (2003, p.20).

The key tenant of the TPS is the elimination of waste, where Toyota identified 7 wastes as follows (Liker 2004).

- *Overproduction* – producing items for which there is no immediate need,
- *Waiting*- workers waiting to carry out the next step in production,
- *Unnecessary transport or conveyance*- the presence of inefficient transport in moving parts or materials between production steps,
- *Overprocessing or incorrect processing*- taking unnecessary steps in the production process,
- *Excess Inventory*- excess raw materials or work in progress (WIP), causing damage, obsolescence or excess transport costs,
- *Unnecessary movement*- wasted worker motion, such as looking or gathering parts or materials and
- *Defects*- production of defective work, repair or rework, inspection resulting in wasteful handling time and effort.

Flow as a production enabler has also been identified in the sphere of operations management (OM) where Hopp and Spearman (1996) developed laws on variability, variability buffering and buffering flexibility. This enabled the development of theory by Schmenner and Swink (1998), one of which is the theory of swift even flow which:

Holds that the swifter and more even the flow of materials through a process, the more productive that process is (1998, p.102).

The concept of flow is linked with an ability to synchronise activities where components arrive on time, with delays minimised and work carried out in the most effective sequence (Rodrigues and Mackness 1998) with flow in work sequence and pace achieving optimal project goals (Aziz and Hafez 2013). This leads to harmonic workflow. However, whilst Goldratt (Rand 2000, Luebbe and Finch 1992) refers to the concept of harmony as flow develops, there is little further evidence in literature as to how people might work in harmony to synchronise their activities to implement synchronised workflow.

2.3.1 Origins of Flow

A literature review discloses that whilst Toyota have established a long term and sustainable use of flow production in the form of TPS there is little about flow production that is uniquely a Japanese or a Toyota philosophical approach. Frank Woollard had developed and operationalised flow production by 1904 in the assembly of steel train carriages and then refined the approach in the production of cars at the Morris Motors at Coventry by 1925 (Emiliana and Seymour 2011). The use of flow production at Morris Motors predated the development of TPS at Toyota by 12 years with Toyota taking a further 18 years to operationalise flow production in 1955 (Shimokawa and Fujimoto 2009). It took Woollard two years to achieve full flow production at Morris Motors (Emiliana and Seymour 2011) where 55,582 engines were produced in 1925 (Andrews and Brunner 1955). In comparison Taiichi Ohno took six years to implement flow production at Toyota (Ohno 1982) producing 22,786 engines in 1955 (Toyota 1988, p 461). As well as JIT, the Morris car plant used U shaped work cells, multi skilled workers, supermarkets, takt time, autonomation, visual controls, quick changeovers, standard materials, products and machine tools and standardised work (Emiliana and Seymour 2011). Woollard’s flow production achieved benefits including meeting customer expectations, reduction of costs and the improvement of labour relations with full utilisation of people’s abilities recognised as a key to successful flow production (Woollard 1924, 1925, 1952a). Woollard describes the implementation of flow at the Morris plant as follows:

Automobile parts do not spring into view as ideal materials to flow, because of the varying shapes of the semi-raw material, the very divergent character of the operations thereon and the accuracy desired. Owing to these obstacles to the flow principle, it is essential for *continuous production that the article to be manufactured be standardised, because, with a sufficiency of similar parts that are rarely altered, the mechanism to provide "flow" can be set and worked economically (1925, p.421).*

Furthermore, Woollard considered engagement with and decent treatment of the workforce as critical to success of flow production and system of production should benefit everyone; consumers, workers, and owners (Emiliani and Seymour Vicarys 2011).

The factory is the means of enabling them to earn a decent living, and they are better citizens if they control their own activities outside the factory. Similarly, men will take quite kindly to new machines and methods if they once realise that they will be dealt with equitably. There is no doubt that the attitude of the employees is considerably influenced by the prosperity of the concern that employs them (Woollard 1925).

Despite the early lead, Morris Motors enjoyed over Toyota in flow production implementation, they could not sustain the initiatives, eventually merging with British Leyland in 1967, who now along with the rest of the British car making industry have been consigned to history. Whilst Frank Woollard implemented a flow production approach very familiar to modern manufacturing eyes, the literature reveals the roots of lean production going further back in time to the Venetian Arsenal.

Literature reveals that by the 16th century the Arsenal was literally using a flow type manufacturing system, with canals used as the production lines. Here, the modern concepts of standardized parts, assembly-line production, specialized work groups, and vertical integration was used. By the 16th century, the Venetian Arsenal was the most powerful and efficient ship and munitions manufacturer in the world (Lane 1934). Covering 60 acres, up to 2000 men were employed within its walls. Concentration of every necessary asset at one spot, division of labour, standard work and close coordination with the government bureaucracy were the keys to the power of the Arsenal. Manufacture used a frame first system, opposed to the traditional hull first method, allowing the frame, once water tight, be floated in the canal network to be outfitted. The Venetian shipyard constituted a 'factory'-type enterprise with an 'assembly-line' around which the principle of the division of labour was meticulously organized (Özveren and Yıldırım 2006). This was driven by scarcity of resources as:

A further consequence of resource scarcity in Venice had been to strengthen the vertical, highly centralized and all-encompassing organization of the Arsenale in accordance with

> *the principles of strategic storage of supplies, economizing logic and the subsequent obsession with quality control (Özveren and Yıldırım 2006, p.15).*

Thus, a flow type production system was literally developed and Lane noted that:

> *Only if the spars, sails, benches, anchors etc. were all neatly stacked and numbered in their appointed places could the equipment of a new galley be so rapidly brought together and put in place that the ship might leave the Arsenal the same afternoon in which the hull was launched. The systematic arrangement of materials was adopted with the appreciation of the saving of the time and labour in assemblage which was thus gained (Lane 1934, p.160).*

By using standardization, the Arsenal became the most successful shipbuilder in Europe. By the 16th century, it could produce a fully fitted out military or merchant ship per day, in comparison to the months to construct similar ships in other European shipyards (Davis 2007, Lane 1934).

The literature review reveals a gap in knowledge on the origins of flow production. It is commonly accepted that flow originated with the Toyota Production System (TPS) (Womack and Jones 2003, Womack et al., 1990, Ohno 1982), with commentators in agreement that lean production should be implemented by “stern” *Sensei* dictating how implementation should take place (Womack and Jones 2003, Womack et al., 1990). Yet, the literature revealed that flow production has a richer and more ancient lineage and is a more intuitive approach that generally acknowledged, where the Venetians were literally using flow production, in the middle ages, enabling them to become the most efficient shipbuilders of the period (Lane 1934). Furthermore, Woollard used flow production in advance of Toyota, but with an understanding of the necessity of workforce engagement. This literature informed the implementation of the research where the researcher sought to utilise workforce knowledge and experience in the lean implementation process and furthermore to seek out evidence of existing lean or lean type knowledge. The next section investigates lean construction, whose development was informed by the principles and philosophy of flow production, whilst engaging the workforce in the implementation process.

2.3.2 Lean Construction

Koskela (1993) conceptualised a flow production model for construction projects and Howell (1999) traces the origins of lean construction to flow production. A central part of lean construction is a systems thinking mindset (Jorgensen and Emmitt 2008). One of the main tools used is the Last Planner System (LPS) (Mossman 2012) where Ballard et al., note that it:

> *Is a system of interconnected parts. Omission of a part destroys the system's ability to accomplish its functions. (Ballard and Tommelein 2016, p.7).*

This is systems thinking approach:

> *Seeing interrelationships rather than linear cause- effect chains and seeing processes of change rather than snapshots (Senge 2006, p.73).*

Lean construction has been developed and implemented by lean construction practitioners since the early 1990's to counter shortcomings in traditional construction practice. One differentiating factor between lean and traditional construction management is explicit theory. Lean construction has developed from two roots (Bertelsen 2002). The first is Lauri Koskela's production informed Transformation, Flow and Value, (TFV) theory where transformation flow is guided by the customer's value proposition. The second is Glenn Ballard and Greg Howell's theory of work production planning operationalised by the LPS, originating from a complex construction projects background.

Koskela and Howell codified seven construction flows (Koskela and Howell 1999). Furthermore, Koskela (2000) challenged the traditional construction model in his thesis, proposing an explicit TFV production theory which incorporated time, where uncertainties in the process as well as the interdependencies between tasks are acknowledged. The theory of production as transformation (Walrus 1954) emerged at the end of the 19th century with production described as the simple transformation of inputs into outputs. Koskela describes a transformation process as the decomposition of tasks into sub-tasks in an endeavour to minimise costs. Each sub-task is assigned to operatives with the assumption that cost minimisation of each part will minimise total production costs (Koskela 2000). Transformation and non-transformation are two, time expending activities, where non-transformation activities include waiting, delay and inspection. Flow production seeks to reduce waste with time compression of the process. Lillian Gilbreth conceptualised production as flow where time is a resource, using a seminal process map detailing the flow manufacture of rifle grenades (Gilbreth and Gilbreth

1922). Woollard operationalised the concept in a steel carriage assembly plant in England in 1904. Finally, Shewhart (1931) conceptualisation production as value generation, where the clients value proposition is understood and achieved. Koskela's TFV theory fuses the three concepts of transformation flow and value. Production flows with variability minimised in the production process, where inputs are transformed as efficiently as possible to outputs, focusing on value to the customer.

Koskela stands out as an academic that addressed the criticism of a lack of explicit construction theory by developing one and then proceeding to research and analyse its embedment. The theory has gained acceptance with the validity of the theory acknowledged by several academics (Biton and Howell 2013, Bølviken et al., 2014). Practitioners confirm the theory's efficacy in enhancing project outcomes (Bertelsen and Bonke 2011), with further research and analysis demonstrating its effect on productivity in arenas such as the Finnish construction industry (Koskenvesa 2010). Koskenvesa and Koskela investigated implementation revealing that high variability results in reduced performance. They note the vital role management play in ensuring collaborative efficient task execution. Yet, there is no evident direction or advice given as how TFV theory may be operationalised. Ballard and Howell made significant contributions to knowledge and addressed the operationalisation shortfall by the serendipitous parallel development of the LPS. The tool was developed over twenty-five years ago, following a participant-observation study tracking supervisors and superintendents as they planned their work on a weekly basis (Ballard 2000). Ballard and Howell proceeded to develop the LPS tool adding to knowledge over time, (Ballard and Howell 1997, Ballard and Howell 2003, Howell and Ballard 1994). The LPS is now widely used from remote areas in Africa to complex projects in the United States on projects as diverse as housing schemes to engineering construction projects (Howell et al., 2011).

The fundamental difference in philosophy between lean and traditional construction practice is demonstrated by the contrasting tools used. PMI favours management by results (MBR), using complex cost and efficiency tools such as the earned value method (EVM) (Kim and Ballard 2010). Lagging indicators measure performance with interventions to adjust performance as required. Yet, MBR fails to take account of complexity and interrelations (Kim and Ballard 2010). Lean construction enables project flow and synchronisation by using simple management by means (MBM) tools, such as the LPS (Hamzeh et al., 2012). The LPS supports activity completion in a timely optimised sequence. Mossman (2012) states that the LPS promotes conversations and relationship building among front line decision makers, enabling collaborative production planning. It also helps to create value, where value is defined as what the end user wants. In production, value also means that each trade does enough so the following trade can deliver as required.

Ballard et al., (2016) describe the distinction between planning and control. Planning involves reaching objectives through design, whilst control is the actioning of plans to reach objectives. The LPS is a system for project production control, whose function is to collaboratively steer projects towards targets. Projects controls, normally derived from Critical Path Method (CPM) outputs, set cost and schedule targets, monitoring progress towards project targets. Both CPM and the LPS are needed. (Ballard and Tommelein 2016). Ballard et al., (2016) in describing the history and evolution of the LPS, says it was developed following the discovery of very poor production planning reliability on construction projects. The first aim of the LPS was to improve workflow reliability, achieved by collaborative meetings between first line supervisors producing weekly co-ordinated work plans, to align DID and WILL (figure 2:1), that is to achieve what we say we will do. The percentage plan complete (PPC), measures the relationship between WILL and DID. However, even with excellent productivity with PPC's of 100%, projects could still fall behind schedule when production planning disregards the master programme. Consequently, a lookahead planning process was added, aligning production planning with the master programme, so that what SHOULD be done is dictated by the master schedule. Yet, in many cases, it proved difficult to progress activities that SHOULD be done per the master schedule. Pull planning was introduced to address this issue. Initially it used reverse phase pull planning with scheduling undertaken in reverse order, driven by the prerequisites of each activity. Soon this collaborative pull planning was used to develop detailed schedules aligned with the master schedule (Ballard and Tommelein 2016). Pull planning is used to collaboratively develop a plan and sequence activities. Planned time periods range from 4 to 12 weeks depending on the lead time required to remove constraints. Planning is undertaken by those involved in delivering the work, who fully understand their own work and have the authority to make decisions. Also, present, are those who can provide information required on aspects of safety, quality, logistics, master programming, etc. Pull planning commences with milestone identification and clarification with planning starting at the latest milestone working to the first, with participants collaboratively agreeing times scales, prerequisites, whilst negotiating the satisfactory conditions for handing off each activity (Ballard and Tommelein 2016).

Daily Huddles (DH) form a part of the LPS. Ballard (2016) notes that it typically consists of a stand-up meeting of groups of interdependent people who share information on commitments completed and any assistance needed. Other authors (Salem et al., 2006, Salem et al., 2005) describe the DH as consisting of a five to ten-minute discussion between the supervisors before the working day starts with an information exchange on what has happened on the previous shift and the expectations for the upcoming shift. DH meetings allow team members to share what has been accomplished previously and what impediments they might have been to cause non-completion (Paez et al., 2005).

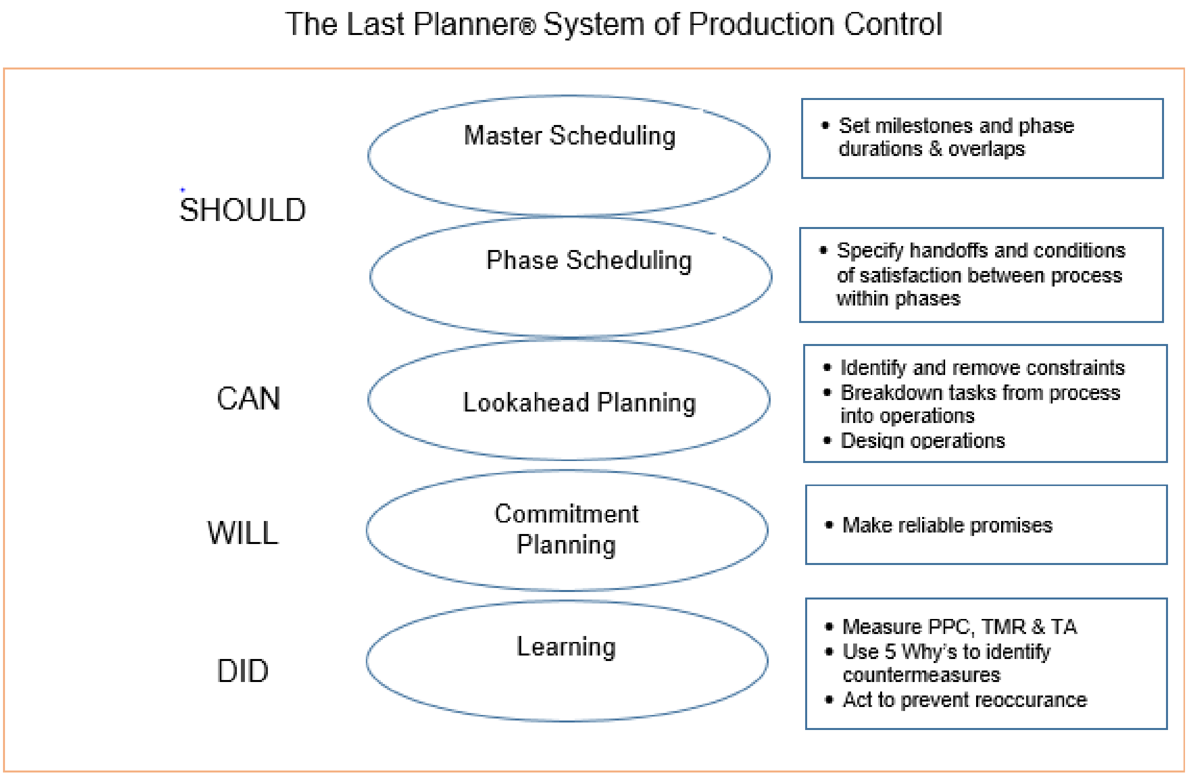

Figure 2:1- Production Control (Ballard and Tommelein 2016, p. 10) Used with permission G. Ballard

Fauchier et al., (2013), analysing data from 30 projects demonstrated that LPS usage fostered collaboration across separate departments, in contrast to previous siloed practice. Furthermore, behaviour exhibited including collaboration, making clear commitments and transparency, active participation of multiple trades, enabling enhanced performance of teams. Research on the implementation of the LPS in New Zealand's construction sector demonstrates a reduction in construction time following involvement of participants in collaborative production planning at the design and into the construction phase. Benefits included the development of close collaborative team building providing enhanced team performance (Fuemana et al., 2013). Elsborg et al., (2004) related that the workforce and management were particularly receptive to the sharing of expertise and knowledge which increased respect and cooperation between trades. There is also evidence of increased job satisfaction with improved commitment to collaborative practice in production planning (Elsborg and Bertelsen 2004, Skinnarland and Yndesdal 2010).

Several authors discuss the use of the LPS as a mechanism aiding learning and knowledge transfer (Fauchier and Alves 2013, Ko, Wang and Kuo 2011). Social learning theory claims that learning emerges from a collective endeavour through human interaction (Easterby-Smith 2002). Learning is socially constructed through the participation of individuals in social processes where socially interactive knowledge management (KM) endeavours assist team development (Hartmann and Dorée 2013, Jones, Mutch and Valero-Silva 2012). LPS aids team learning (Howell et al., 2011), the development of trust in teams, enabling the development of a "socio-cultural learning environment" where meetings become forums promoting experimental learning (Kalsaas 2012, p.96). Aslesen and Bertelsen (2008) note that human aptitudes for learning, intuition and adaptability positively influence the application of the LPS, with learning gained from analysis of breakdowns in planning, to identify the cause and future countermeasures (Ballard and Tommelein 2016). Furthermore, lean construction advocates note that lean facilitates learning and knowledge transfer (Kalsaas 2012, Alves et al. 2012), with first run studies (FRS) as one proposed enabler (Ballard and Howell 1997). This uses participants existing knowledge in the development of learning and continuous improvement. Ballard and Howell note that:

> *The intent is to thoroughly plan and study first run studies of operations, using past studies as guidelines and producing standard work method designs for use on the project. This experiment-based approach produces a tested method that can be taught to all crews, thus reducing cost, errors and accidents... once workers see that you are interested in finding better ways of doing work; they will develop and share their ideas.* (1997, p. 215).

Yet, for the most part the learning aspect has not been "problematised" (Kalsaas 2012). There is a gap in literature, that whilst the merits of FRS in the development of standard work is understood, there is little discussion on operationalisation. There is some discussion by Nguyen et al., (2009) on the subject in an article on the development of a damping beam on a project in San Francisco. In this, virtual first run studies (VFRS) were implemented, where cross functional groups of specialist contractors used tools including choosing by advantages (CBA), process mapping and building information modelling (BIM) to develop a viscous damping beam wall to earthquake proof a hospital project in San Francisco. VFRS is defined as a first-run study carried out in a virtual environment such as a BIM computer model, to develop a prototype, tested and improved following feedback from a Plan, Do, Act, Check (PDCA) cycle to develop a standardised solution. Furthermore, there is some evidence of the use of continuous improvement (CI) cells by Highways England (HE) in the UK, which can inform FRS implementation. Here cells or groups of decision makers employ a visual management approach using white boards populated with visual information to provide a focal point to inform FRS implementation (Highways England, 2015).

However, whilst generally used in manufacturing there is little evidence of the use of prototypes in construction (Hackett et al., 2014), even though greater standardisation of products, processes, and project organisation aids construction project workflow reliability (Santos et al., 2002; Josephson and Samuelsson, 2009). Value delivery to the customer in construction projects can be reduced by standardisation which aids uncertainty reduction and improves continuity (Gadde and Håkansson 2001, Samuelsson 2006), with reliability improvements achieved through greater standardisation of products, processes and project organisation (Santos et al., 2002). One reason for limited usage is management resistance to the concept of standardisation due to the perceived lack of control engendered by the process of standardised work (Polesie and Frödell 2009).

The development of standard work can also be referred to as work structuring. Work structuring is the development of process and design with the goal of making the work flow more reliably whilst providing value to the customer (Tsao et al., 2004). Work structuring, also referred to as production system design involves both designing and making products. This has three goals: to do the job, maximize value, and minimize waste (Ballard et al., 2001).

However, the literature almost exclusively reports on standard work development undertaken by management, designers and architects (Yu et al., 2013) with little evidence of workforce input. Yet, Seddon (2003) notes that those who carry out are in the best position to develop procedures and plans guiding implementation. improved standard work design. Seddon notes that the workforce is in the best position to lead the design and implementation of flow approaches. He gives an example where members of the workforce set about redesigning inspections on housing repairs for a local authority.

> *They visited each site where values were out of specification and determined the reasons why. They then added to the team all the expertise required to rectify the various situations… the team set about reducing variation... they were proud of their achievement and knew how to work to maintain the purpose (2003, p.95).*

Whilst literature indicates the potential of the LPS to aid learning, there is a considerable gap, in that the learning aspect has not been “problematised” (Kalsaas 2012). Pasquire closed the gap somewhat, proposing a concept of common understanding. She notes that this is the 8th flow, of equal importance to the other construction process flows. This concept develops a rationale as to why the lean tools facilitate learning and knowledge transfer (Pasquire and Court 2012). Pasquire notes that people on construction sites work in unpredictable ways, in some part due to a lack of shared understanding, demonstrated by failure to notice glaring clashes, errors and defects. The concept was explored during a hospital construction in the UK (Pasquire and Court 2012, Pasquire and Court 2013). However, there is little description of how “common understanding” can be operationalised.

There is a further facet in the knowledge transfer equation, which is its enhancement of higher performing teams. Chinowsky et al., (2008) notes that high performing teams in construction projects can produce “innovative solutions” which consistently confounding expectations. These teams are identified by their ability to exchange project information, knowledge, insight, thereby enhancing the group’s capabilities. Britt (2014) used ethnographic research to investigate and demonstrate the LPS aiding the development of high performing teams on a hospital construction project in the US. Even so, for the most part these teams evoke little interest in the construction domain, which is more fixated on time, quality and cost benchmarking (Chinowsky, Diekmann and Galotti 2008).

Many academic and practitioner papers report successful outcomes from the use of the LPS. This includes, research and subsequent analysis into benefits achieved on implementing the LPS on a housing project in Quito, Ecuador (Fiallo and Hugo- Revelo 2002), on industrial and commercial projects in Brazil (Formoso and Moura 2009) and on transport rail construction projects in India (Sripriya, Pratap and Vidjeapriya 2013). There is also some advice on how to implement the LPS. Howell outlines nine implementation steps, including “building the team” (Howell and Macomber 2002, p.5) and “establish practices for improvement” (ibid. p12). Mossman (2012) also provides some general advice on LPS implementation. Still, even now the literature describes difficulties encountered whilst implementing lean tools and points to reasons for implementation failure. These including difficulties encountered in the development of effective knowledge sharing tools (Chesworth 2015), embedment barriers including a lack of appropriate training, a lack of senior management support, an inability to motivate people, a lack of honesty and trust between participants and a failure to select and train the right people (Cano et al., 2015). Simonsen et al., (2014) note that the concepts can be difficult to sell, because of a lack of quantitative data benchmarking and comparing outcomes with more traditional approaches and a lack of balance between academics and practitioners.

There is evidence of lean construction used as an antidote to the productivity shortfalls experienced in engineering construction (EC), including implementation research, during spool assembly on an industrial engineering project in the US, (Wang et al., 2009). Also, Morgan et al., (2012), describe some partial implementation of lean approaches used in the completion and commissioning scope of work on the Pluto LNG project. Yet, there is no evidence that this initiative was sustained on other contracts. Literature also reveals further implementation of lean construction in the Australian engineering construction industry. Nguyen (2013) reports on workshops delivered to clients in engineering construction, briefing them on lean construction tools. Currently, Fernandes (2016) propose the development of a standardised lean construction manual and Mejia et al., (2016) have carried out research using benchmarking to seek potential improvements in the use of the LPS. Still, little detail is offered on the implementation of lean construction itself, with little evidence of longitudinal research undertaken to develop clear implementation guidance.

The literature search uncovered further gaps in literature. Whilst the potential of the LPS to assist team learning is acknowledged, there is little evidence of recommendations on operationalisation. Pasquire (2013) closed this gap somewhat by proposing the concept of the 8th flow, common understanding, to assist learning by knowledge transfer. But no direction has yet been offered on operationalisation of the concept. Furthermore, Chinowsky et al., (2008) note that knowledge transfer assists the development of higher performing teams from existing ones, but says there is little interest in this in the construction industry. In response, the researcher developed a tool called Team Work Design (TWD) where teams doing work, design the work using FRS in PDCA iterative cycles, assisting the creation of high performing teams from existing ones, by aiding the development of the 8th flow between team members (Hackett et al., 2015).

Nonetheless, whilst the benefits of lean construction are demonstrable, the approach has its critics and the following section investigates some of these criticisms.

2.3.3 Criticisms of Lean

Whilst the lean approach represents a fresh approach to production both in manufacturing and construction, the approach has its critics. They perceive a gap between the rhetoric and practice of lean approaches, particularly with its effects on the workforce. They note that the work environment generated by lean production can be de-motivating, incorporating restrictive practices, with little actual regard for worker skill development (Babson 1993, Rinehart et al., 1997, Berggren 1993). It is “work intensification” (Berggren 1993) with scant opportunity for enhancement or development of individual potential. Green (1999) says that lean advocates ignore the body of literature addressing the human costs of lean production, noting that interpretations developed by Womack et al., (1990) from their research on the Toyota TPS sits “uncomfortably” close to the principles disseminated by Fredrick Taylor (1911). Green and May (2005) note a lack of understanding and vagueness about the meaning of “leanness” among practitioners in construction, mirroring that found in the literature. Within the body of lean literature:

> *Little recognition is given to the socialised nature of the diffusion process (Green 2011, p.239).*

Organisations can have a unitary perspective, assuming commonality of purpose and aims in organisations, with senior management regarded as being “omnipotent, omniscient and unified” (Marchington and Vincent 2004, p.1030). All others in the organisation are expected to implement strategies as directed with no recognition of the probable existence of conflict or power machinations, which might act against embedment of organisational change. Green asserts that lean construction practitioners also exhibit a unitary perspective (Green 2011). Moreover, Green views the use of lean construction in the UK as another cynical ploy in the continuing “hollowing out” of the industry. Firms implement lean using agency labour, abdicating responsibility to their workforce, in a race to the bottom with a workforce consisting of:

> *Vulnerable self-employed operatives with limited rights to welfare provision, sick pay and pension contributions (Green 2011, p.256).*

The literature revealed criticisms of lean with a gap demonstrated between rhetoric and practice. Lean implementation can be unitary in practice, with a lack of senior management awareness of plurality of views regarding the change management implementation. Furthermore, the implementation of lean construction can be a cover for a further hollowing out of the construction industry with scant regard for the effect on the workforce and little effort made to engage them in change implementation. In the researchers experience of working in the industry these criticisms are not unfounded. To address the arguments above literature on human potential was investigated as described in the following section.

2.4 People potential and its facilitation

People potential takes a view that workers have a greater level of tacit and explicit knowledge, and expertise in their domains than management. As a result, they are in a better position to plan and schedule their work, as well as having the ability to identify and remove the constraints that would impeded the work flow (Morgan- Tuuli and Rowlinson 2009, Cooke 1994). Brown (2007), notes that construction performance is influenced by the human capital of its participants. Human capital is the available human resources in terms of skills, knowledge, experience and capability of a workforce. Capability is an attribute, which is the knowledge and skill possessed by people or organisations. Knowledge and skill are accumulated through learning, gained through “doing” or observation of what others are “doing” (Day et al., 2004). Dakhli and Clercq (2004) also note the importance of human capital aided by social capital in the development of innovative practice. Tsai and Ghoshal (1998) proposed the concept of social capital, outlining three components, cognitive, relational and structural. The cognitive component refers to the development of shared understanding by shared mental models. The relational component refers to the network relationships and social interaction to ties that foster the development of trust and trustworthiness (Day et al., 2004). The structural component refers to a person’s position in a network in relation to other individuals. Social capital assets within project based organisations aids knowledge transfer, thereby enhancing performance levels (Di Vincenzo and Mascia 2012).

2.4.1 Knowledge Management

The concept of knowledge and its constituent parts is something that philosophy has pondered down through the centuries since the classical Greek period, with a branch of philosophy, epistemology dealing with the origins of knowledge. Plato defined knowledge as justified true belief and Boisot (1998) notes that knowledge is constructed from information built up from data. Data is a discernible difference between states, which may convey information depending on an agent’s knowledge. Information is discernible patterns, filtered from data, dependent on preconceptions and existing knowledge stock. Data and information are tangible and can be directly observed. Knowledge on the other hand can be intangible and may be conceptualised as the expectations of the outcomes of events, expectations that can be modified or confirmed with new information (Boisot 1998). Newell et al., note that knowledge can be either explicit, which can be codified and written down or tacit, which is difficult to articulate, and:

> *Enacted through the practices of different groups and inextricably bound up with the way these groups work together and develop shared identities and shared beliefs (Newell et al., 2009, p.4).*

Michael Polanyi, a scientist and a philosophical thinker initially conceptualised tacit knowledge. Tacit knowledge is internalised personal knowledge, difficult to verbalise. This was a concept running counter to modern science thinking at that point in time, as modern science seeks detached objective knowledge at the expense of tacit knowledge (Polanyi 1966). Polanyi saw knowledge as “unspecifiable”. Knowledge is indefinable and:

> *Indeed, even in the modern industries, the indefinable knowledge is still an essential part of technology…. An art that cannot be specified in detail cannot be transmitted by prescription, since no prescription for it exists. It can only be passed on by example from master to apprentice... It is pathetic to watch the endless efforts, equipped with microscopy and chemistry, to produce a single violin of the kind that the half-literate Stradivarius turned out as a matter of routine more than 200 years ago, (Polanyi 1958, p.53).*

Explicit knowledge forms a small part of the overall store of human knowledge, in effect the tip of the knowledge iceberg. Nonaka et al., (1995) reference Polanyi’s seminal conceptualisations as they developed the SECI (socialisation, externalisation, combination and internalization) model for knowledge transfer within an organisation. The SECI model is described as a knowledge spiral where tacit knowledge is churned through an organisation by a process of socialisation, externalisation, combination and internalization. The authors note that Western thinking tends to emphasis explicit knowledge whilst Japanese thinking stresses tacit knowledge. Yet, knowledge comprises both tacit and explicit elements. The authors describe some examples where tacit knowledge was codified for organisational usage. These include the Matsushita Electrical Industrial Co. Ltd that developed an electric dough mixer, which could replicate the unique mixing action of the artisan bread makers and “embody” this in the mixing action of the dough maker. However, Polanyi’s says that in general tacit knowledge cannot easily be converted to explicit knowledge for exploitation by an organisation. Polanyi sees tacit knowledge as “indefinable”, its transmission dependant on the nature of the relationship between “master and apprentice”.

Increasingly, due to its complexity, interrelated groups of specialists collaboratively carry out work activities (Bechky 2003) with organisations tending to use standard operating procedures to capture localised contextual knowledge (Huber 1991, Levitt and March 1988). Yet, the complex and tacit nature of knowledge render the use of this codification largely ineffective (Nonaka and Takeuchi 1995, Kogut and Zander 1992). Likewise, the general construction industry also uses knowledge management initiatives with “lessons learned” collected once projects are complete. Generally, workshops are used to collect explicit knowledge for use on future contracts (Carrillo et al., 2013). Yet, lessons learned rarely inform subsequent projects (Paranagamage et al., 2012), become lost (Carrillo et al., 2011) and contextualised tacit knowledge is difficult to capture and store in IT systems (Malhotra 2000).

Orlikowski (2006) refers to a “scaffolding of knowledgeability” which supports the transfer of knowledge between teams. These include physical objects, artefacts and rules which support and guide activity whilst providing structure and discipline. These supports the accomplishment of complex work activities (Clark 2002). Nicolini et al., (2012) refer to these as boundary objects. This concept was developed within the field of science studies where boundary objects are defined by their capacity to serve as bridges between intersecting social and cultural worlds (Carlile 2004, Levina 2005). Boundaries present barriers to knowledge transfer (Newell et al., 2009). Carlile (2002, 2004) identified three boundaries; syntactic, semantic and pragmatic. Syntactic boundaries are created by differences across groups in terms of the use of different language, grammar and symbols. Semantic boundaries are caused by differences in accepted interpretations and meanings, where knowledge needs to be translated rather than just transferred. Examples include the different interpretation of risk between those from an engineering and legal backgrounds. Pragmatic boundaries occur when groups involved in collaborative practice have differing or conflicting interests, where solution agreement is stymied by self-interest (Newell et al., 2009). A range of objects can become boundary objects, including standardized forms, sketches and drawings (Carlile 2002), physical objects, prototypes (Star and Greismer 1989) and narratives (Bartel and Garud 2003). Currently, Koskela (2016) notes the use of boundary objects to facilitate collaborative working.

Another factor that affects team performance and knowledge transfer is team size, described below.

2.4.2 Team Size

The size of the team determines the efficiency of knowledge transfer. Analysis on the quality of teamwork and team behaviour demonstrate that teams have a complex nature (Hoegl and Gemuenden 2001). Nicholson (2000) notes that people function best in family groups of five to nine members and Rodriguez (2012) that there is a marked decrease in productivity once membership exceeds nine. The quality of teamwork depends on six teamwork quality facets: communications, co-ordination, balance of members' contributions, mutual support, effort and cohesion (Sethi and Nicholson 2001). Highly collaborative teams utilise all six facets in their social interactions (Cummings 1978). However, the complexity of the interconnections increases as the number of members increase, exerting a drag on the transfer of knowledge, skills and experience across the team, to the point where teams with more than nine members cannot be expected to perform high quality teamwork (Hoegl 2005).

Graham Turner demonstrates how the application of the concept of limiting team size works within the context of a global organisation. In 1981 in the UK, he set up the forerunner to The Flight Centre Travel Company. In 1995, after reading Nicholson's "Managing the Human Animal" (2000) he limited team sizes to a maximum of nine members throughout the organisation and noted that

> *In contrast, the company experienced less success when it tried to set up larger groups (Johnson 2005, p.128).*

The company reported a profit of $420million on a $17.6 billion turnover in 2015 (Flight Centre 2015). Flight Centres ability to grow year on year runs counter to the trend within the travel industry over the last number of years, which have faced headwinds from the global recession, the growth of online travel booking and the rise of disruptively innovative travel companies.

The following section investigates literature search on social aspects of teams including the role of informal leaders.

2.4.3 Informal Leadership

Pescosolido notes that an informal leader is a person who:

> *Exerts influence over other group members. Other studies involving informal leadership have added to this definition by saying that an informal leader comes from the team and is chosen by the team. Some literature has further defined that the informal leader does not*

receive special compensation or rewards and that the informal leader does not hold the power of hiring and firing (2001, p.78).

Ross (2014) notes that informal leaders may not have formal authority to direct a group but are willing to stand up and act. Hills (2014) notes that informal leadership is the ability to influence the behaviour of teammates through means other than formal authority and they can influence team members to achieve at higher levels than normal. Pescosolido (2001) states that informal leaders in a group play a key role in developing group efficacy and Zhang et al., (2012) note that a shared team vision encourages the emergence of informal leaders.

Day confirmed that the identification and engagement of informal leaders would be key in the quest to the sustainable embedment of the lean tools in this or any other environment. On the question of leadership, he expresses that leaders can have informal as well as formal authority and:

Leadership development involves building the capacity for groups of people to learn their way out of problems that could not have been predicted, or that arise from the disintegration of traditional organizational structures and the associated loss of sense making (Day 2000, p.582).

2.4.4 Culture

Culture impacts on performance (Casson 1993) and therefore has become an area of interest in construction industry (Fellows 2010). Culture can be defined as:

The collective programming of the mind which distinguishes the members of one group or category of people from another (Hofstede 2008, p. 9)

Organisational culture is characterised by values and norms. Values are deeply held beliefs and norms are shared social attitudes about acceptable behaviour, exhibited in the informal social networks, stories and heroes that have developed over time (Tushman and O'Reilly 1997). Organisational culture influences construction project performance, and enables knowledge transfer in organisations (Adenfelt and Lagerstrom 2006). Organisational culture aligns with corresponding national cultures in the construction industry (Liu and Fellows 2008) where the national culture influences behaviours, values and construction practice (Liu et al., 2015). Cameron and Quinn (2011) report four types of organisational culture, which are, “clan”, “adhocracy”, “hierarchy”, and “market” culture. Clan culture values loyalty where teams participate together with success determined by the value provided to the customer. Adhocracy culture places high importance on innovation, creativity and personal initiative with success framed in developing unique products and being a market leader. Hierarchy cultures lead to organisations with value placed on being dependable and these tend to have formalised hierarchical structures. Finally, reputation and market leadership are valued in market cultures with an organisational focus of achieving specified goals (Cameron and Quinn 2011). Research on culture in the construction industry demonstrates global variations. American projects tend towards a clan orientated culture, with loyalty and collaborative teamwork valued, (Oney-Yazici et al., 2006, Arditi et al., 2017). Success is measured in terms of fulfilling customers' requirements (Cameron and Quinn 2011). On the other hand, a market organisational culture dominates Indian construction where organisations are results driven, with value placed on market leadership and reputation and success regarded as the level of market share achieved (Cameron and Quinn 2011). Research undertaken by Dastmalchian et al., (2000) showed that economies determine cultural variations. Organisations operating within unpredictable economies such as India tend towards market cultures, whilst predictable economies such as the US tend towards clan organisational cultures in construction companies.

A particular culture can be gauged by the visibility of artefacts (Schein 2004). Artefacts include what one feels, sees and hears when encountering an unfamiliar group. Bettinger (1989) identifies 11 artefacts which signify a "good" organisation. These include the sense of pride in the company, attitude towards change, the level of openness, communication and information sharing, commitment to effective teamwork, values that contribute to defined successful outcomes, an atmosphere that reduces conflict and enhances collaboration, the level of employee participation in decision making and a system that rewards good performance. Ankrah using statistical ANOVA analysis investigated the relationship between culture and performance on construction projects, reports the following cultural artefacts as important contributors to construction project effectiveness. Higher performing projects have higher team orientation, where effort is expended on enhanced workforce motivation, teamwork with open communication across projects including information to the workforce, have tidy sites, a positive affirmation of good performance, participation in learning, decision making and effective planning with good management/workforce communication (Ankrah 2007).

Wong et al., (2011) notes gaps in research into construction projects organisational culture. These have included a lack of clarity on organisational culture in construction. There are further gaps in literature with little evidence of research into perceptions among the workforce in general and workers operating in the EC industry in particular.

2.5 Conclusion

The engineering construction (EC) industry in common with the general construction industry suffers from low productivity levels, an issue also endemic in the Australian oil and gas industry. Due to the shortage of EC research, construction literature was reviewed to provide a theoretical foundation to develop inferences for EC. As noted, while some reports points to workforce issues (Ellis and Legrand 2013, other literature search reports a relatively well-educated and capable workforce with outputs matching the best seen globally (BCA 2013). Existing in depth research draws attention to other factors, including the lack of professionals having experience in the construction of large-scale resource projects. However, there appears to be a shortfall of quantitative research and analysis undertaken in the EC industry with only one apparent stand out researcher; Ed Merrow (2011).

Research into construction productivity is sparse for the most part, probably because it is “difficult” to do (Eastman and Sacks 2008). There are some stand out researchers in the field such as Randolph Thomas, whose research, supported by other researchers, points to variability as being one of the major productivity restrictors in a construction process. However, research into productivity requires a considerable amount of data collected for statistical analysis. The literature exposed the difficulty in measuring construction productivity. However, it also disclosed a correlation between productivity and performance levels with performance expressed in terms of cost, quality and time outcomes. Performance may be defined in terms of cost, schedule and quality outcomes (Kerzner 2006), or measured in terms of schedule, quality, environmental impact, work environment and innovation outcomes (Eriksson and Westerberg 2011). Therefore, the research used time and innovation outcomes to measure performance change

Literature revealed research undertaken on culture in the construction industry with organisational cultures mirroring the corresponding national cultures (Liu and Fellows 2008), where the national culture influences behaviours, values and construction practice (Liu, Meng and Fellows 2015). Cameron and Quinn, note four types of organisational culture; clan, adhocracy, hierarchy, and market culture. Culture affects construction project performance. Collaborative construction projects, expend resources to enhance workforce motivation, teamwork, open communication across projects including information to the workforce, site tidiness, positive affirmation of good performance, participation in learning, decision making, planning and good management/workforce communication, the presence of which indicates high performance levels (Ankrah 2007). Literature revealed a paucity of research on workforce culture in the engineering construction industry. The primary research used longitudinal research to close this gap.

Gibson (2009) in his report on the UK EC industry identifies a failure to involve the workforce in planning as a reason for low productivity levels experienced in the UK industry. Lean construction addresses this by using approaches including the LPS, a collaborative lean tool with decision makers evaluating and committing to work activities before execution (Ballard and Tommelein 2016). The LPS supports activity completion in a timely optimised sequence, promoting conversations and relationship building among front line decision makers, enabling collaborative production planning (Mossman 2012). It also helps to create value, where value is defined as what the end user wants. In production value also means that each trade does enough so the following trade can deliver as required.

The LPS, used during the primary research is dependent on milestones provided by the master programme. The master programme is normally produced on construction projects using the Critical Path Method (CPM). The literature revealed issues with the complexity of the software and understanding of the outputs by the workforce, but also a gap with a shortage of research of its use in EC. The thesis addressed this gap using quantitative and qualitative data analysis.

Several authors discuss the use of the LPS to aid learning and knowledge transfer (Fauchier and Alves 2013, Ko et al., 2011). Ballard and Howell report that lean approaches such as the LPS not only encourages collaborative production planning but also aid team learning (Howell et al., 2011). Aslesen and Bertelsen (2008*)* note that human aptitudes for learning, intuition and adaptability positively influence the application of the LPS. Ballard et al., (2016) declare that the LPS can facilitate learning from plan failures by analysis of breakdowns in planning, to identify the cause and future countermeasures. There is evidence of some lean construction research investigating the benefits lean construction provide in team learning and knowledge transfer with Pasquire (2012) expanding on this by conceptualising common understanding as the eight flow. Yet, there is still a gap in literature with little obvious research on the operationalisation of the eight-flow concept. Also, Seddon (2003) notes that the workforce is best placed to design and test their own standard work. In response, the primary research implemented a tool referred to as Team Work Design (TWD) using first run studies (FRS) as part of a plan do check act (PDCA) cycle, to facilitate the development of common understanding by knowledge transfer and leaning between and among teams. It was also implemented to assist the transformation of higher performing teams from existing ones.

The literature revealed current challenges experienced with the implementation of lean construction initiatives and there is a gap in literature with little evidence of research investigating the longitudinal implementation of lean construction to develop implementation guidance. To address this, the research identified approaches that aid development of good team practice in domains other than construction. These included the use of boundary objects, informal leaders and control of team size. The literature on team size informed the implementation of the primary research where team size, where possible were set at a maximum of 9 members at forums such as the Weekly Work Plan (WWP) meetings and pull planning workshops. Findings aided the development of implementation guidance.

Furthermore, the literature revealed misconceptions regarding the origins of flow production. The accepted narrative says that flow is a Japanese informed philosophy, the genesis of which occurred in the 1950's. However, the literature demonstrates the use of flow production in the middle ages in the construction of ships at the Venetian Arsenal and then used by Woollard at the beginning of the 20th century. This gap informed the implementation of the primary research where the research was open to the possibility that a flow approach could be instinctive, with the workforce members having a greater ability to initiate and lead good practice than traditionally recognised.

The following chapter describes the design research and methodology employed over the course of the research.

3 Research Design and Methods

This chapter outlines how the research was undertaken and describes the methodological considerations, the research design and the methods chosen from the available research methods. The strengths and weaknesses of the available methods are discussed, as are the reasons for using the method chosen; action research.

3.1 Methodological Considerations:

The construction research community is engaged in an ongoing debate on appropriate research methods. Construction research is a relatively new field, drawing research strategies from natural and social sciences. Fellows and Liu (2008) note the dominance of the positivist approach with its emphasis on quantitative methods with the result that research has been skewed towards “natural science” strategies. Some academics (Seymour and Rooke 1995, Rooke et al.,1997) agree and note that the research culture needs to change if construction research is to have any meaningful impact on the industry itself. Yet, Bryman notes the differing perspectives of positivism held by authors.

> *For some writers, it is a descriptive category, one that describes a philosophical position that can be discerned in research… for others it is a pejorative term used to describe crude and often superficial data collection, (2012, p.32).*

Nevertheless, at odds with these criticisms, lean construction literature demonstrates a substantial amount of practitioner and academic case study and ethnographic research. This includes ethnographic research investigating the implementation of the LPS on a hospital project (Britt et al., 2014) and case studies including one on the social aspects on the implementation of the Location Based Management System (LBMS) (Freeman and Seppanen 2014).

3.1.1 Epistemology

Epistemology is the philosophy about the origins, uses and limitations of knowledge (Fellows and Liu, 2008). The broad range of epistemology available to form a philosophical underpinning to research can be visualised as a continuum that stretches from positivism on one end to interpretivist on the other end.

Positivism asserts that truth consists only of non-metaphysical facts and observable phenomena. Facts are something that can be observed and measured, remaining uninfluenced by observation and measurement. Research can only be undertaken using quantitative methods, with causality determined using observation and measurement, where hypothesis is tested to be accepted or rejected in the development of theory by hard scientific methods (Fellows and Liu 2008).

Interpretivism on the other hand requires an emphatic understanding of human behaviour and a grasp of its subjective nature (Bryman, 2012). Fellows and Liu (2008) note that in this philosophical stance a person's "reality" is determined by such factors as upbringing, education, life experiences and training. This research was informed by an interpretivist philosophy as it focused on the social aspects of human interactions and behaviour. Crotty (1998) notes the intertwined nature of ontology and epistemology makes it difficult to describe one without reference to the other.

3.1.2 Ontology

Blaikie defines ontology as:

> *Claims and assumptions that are made about the nature of social reality, claims about what exists, what it looks like, what units make it up and how these units interact with each other. (2000, p.8).*

Further examples of ontology positions include objectivism and constructivism. Objectivism is:

> *An ontological position that implies that social phenomena confronts us as external facts that are beyond our reach, and constructionism is a position that challenges the suggestion that categories such as organisation and culture are pre-given and therefore confront social actors as external realities that they have no role in fashioning, (Bryman 2012, pgs.32-33).*

Bryman (2012) notes that constructivism is an ontological position asserting that social interaction is the primary driver producing "phenomena" and artefacts which are in a constant state of flux. The research focuses on social aspects, investigating how a workforce interacts with the lean construction approach in an engineering construction project. Therefore, constructivism was the ontological perspective adopted for the research again due to the investigation of the social aspects of Engineering Construction (EC) construction projects.

3.2 Research Design

Creswell notes that research designs are "plans and procedures for research". These provide a framework and guide the research:

From broad assumptions to detailed methods of data collection and analysis (Creswell 2009).

The researcher must bring their experience and philosophical worldview to the research process; informing the selection of methods used, which includes qualitative, quantitative and mixed methods. The available research methods are described below.

Action Research (AR)

AR integrates "learning by doing" where learning is aided by reflection (Coughlan and Bannick 2012). Learning is used to bring about change, by an interaction with the very people who do the work and who will eventually sustain the change, if worthwhile. AR combines continuous experimentation with analysis using many forms of data and evidence. By examining the process and outcomes of the action, explanations and further ideas are forthcoming, setting the platform for new action (Burns 2007).

Coughlan et al., (2012) note that AR investigates both organisational issues themselves as well as the people caught up in these issues. AR is about contributing to practice and creating knowledge (McNiff and Whitehead 2012).

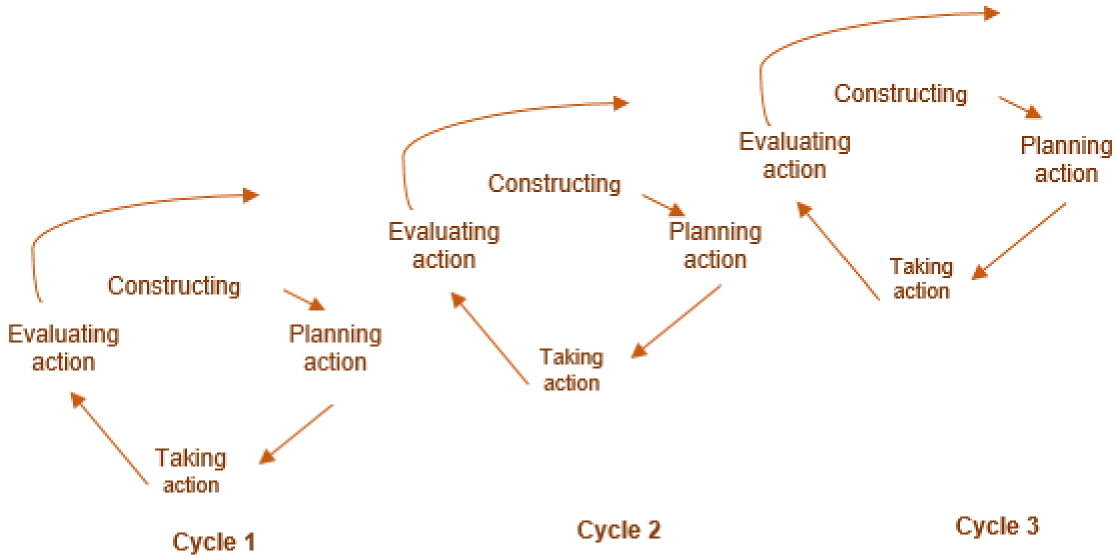

Figure 3:1- Spiral of AR Cycles adapted (Coughlan & Brannick, 2012, p. 10)

The “constructing” phase (figure 3.1) is a “diagnostic activity” where stakeholders in an organisation collaboratively examine and gain an understanding of issues where iterative changes can be made and embedded in the organisation. “Planning action” uses the outcomes from the “constructing” phase, where the team collaboratively plan how the change event identified may be implemented. This is followed by “taking action” where the team itself “take action” and then evaluate outcomes to continue the process in subsequent cycles. The approach was used as it enabled the iterative implementation of lean construction in a collaborative process with the workforce including supervision and management in successive projects, learning from past cycles to institute improvements in subsequent cycles.

Experimental Design Research

Experimental research uses empirical data to establish a posteriori knowledge, which is scientific knowledge that is supported by empirical evidence rather than intuitive reasoning. Discoveries and contributions to knowledge are based on logic. Causality is established with relationships demonstrated between cause and effect (Bernold and Tai 2010). Shadish et al., note that its distinguishing feature is clear and important:

> *That the various treatments being contrasted (including no treatment at all) are assigned to experimental units by chance, where the random assignment creates two or more groups of units that are probabilistically similar to each other (2002, p.12).*

Three groups may be used, a control group consisting of teams using traditional methods, an experimental group, consisting of teams using an experimental intervention and a comparison group made up of teams using a similar intervention to the experimental. Comparison groups provide data about the counterfactual inference, what would happen if the treatment had not been applied (Shadish et al., 2002) with validity of causal inference strengthened, if no or differential changes occur in the comparison group following treatment (Parker, 2003). This approach was used in the first cycle but then abandoned, for reasons described below.

3.3 Implementation the Research

The Research Design

The research aim and objectives were set by the literature search which revealed several gaps. The research proposed was the investigation of the implementation of lean construction on the ongoing refurbishment of an LNG plant; the KGP. Quantitative research was used to analysis secondary data to determine issues impacting on performance. Experimental research design was used initially, but difficulties in implementation forced a change to Action Research (AR). Issues included a reluctance by participants to populate questionnaires and practical difficulties in having control and experimental groups working in a tightly coupled manner on the refurbishment. Thus, AR was used to investigate the implementation of the Last Planner System (LPS) and a tool described as Team Work Design (TWD) on seven cycles of discrete refurbishment projects allowing the interaction and participation of those involved in the research process. Knowledge, gained from literature assisted this implementation process.

3.3.1 Team Size

Researcher experience and the literature review on team efficacy revealed team size as a determining factor of team performance, where performance diminishes appreciably once team numbers exceed 9 individuals. Therefore, where possible the number of people involved in lean forums and meetings were maintained at 9 or less. It proved more difficult to control numbers at the daily huddles due to the number of people who wanted to be involved. As well as the team size, there are other considerations in optimising team performance. This is the use of boundary objects, described as follows.

3.3.2 Use of boundary objects

As noted in chapter 2, boundary objects assist in knowledge transfer and can consist of drawings, documents, pro- forma, white boards, narratives or discussions. The boundary objects used during the lean implementation included the standardised weekly work plan (WWP) meeting sheet, the post-its, whiteboards and narratives used in the pull planning and the TWD workshops used to develop standard work. Taking cognisance that boundary objects promote

> *deep emotional holding power and generate intimate attachment that creates*

social bonds (Nicolini et al., 2012, p. 614).

the boundary objects were normally left in the" raw state", either as the handwritten sheets, or the post-its left in place on the walls. The boundary objects used in the process of implementing the lean tools were most effective when individuals were fully engaged in events such as the WWP meetings, the pull planning and TWD workshops.

3.4 Quality of Research Designs

Porter (2007) notes that research is a form of communication, requiring a rigorous approach to ensure its veracity. Lincoln and Guba(1985) proposed four criteria for establishing rigour which are, internal validity, external validity, reliability and objectivity. Yin (2009), explained and operationalised the implementation of validity and reliability criteria, describing them succinctly as follows:

- *Construct Validity: identifying correct operational measures for the concepts being studied.*
- *External Reliability: defining the domain to which studies can be generalised.*
- *Reliability: demonstrating that the operations of a study- such as the data collection procedures – can be repeated with the same results (2009: p 41).*

3.4.1 Construct Validity

Shadish et al (2002) say that construct validity:

Involves making inferences from the sampling of a study to the higher order constructs that they represent (2002: p65).

Denzin and Lincoln (2011), add that construct validity refers to the extent a case study has investigated what it claims to have investigated with two main tactics used to it. Firstly, triangulation, using different sources and data collection techniques including observations, questionnaires, interviews and archival information (Yin 2009, Denzin and Lincoln 1994). The evidence can be either qualitative or quantitative. The second strategy is to develop a clear chain of evidence. The following section describes how the first strategy was implemented.

3.4.1.1 Triangulation

Fellows et al., (2008) note that the combined use of qualitative and quantitative techniques can produce triangulation to assist in providing rigour in the conclusions and findings drawn from research. By employing a combination of the qualitative and quantitative, the disadvantages of each may be reduced or eliminated. In addition, the combination of both may provide support and strengthen the advantages of each by providing "bridges" between the two perspectives.

The research used methods triangulation where firstly longitudinal observation was undertaken to investigated the particular culture at the KGP. Here, the researcher observed the KGP culture and environment to inform the implementation of the lean tools. Semi-structured interviews were used to investigated the implementation of the Critical Path Method (CPM), which produces milestones that inform LPS production planning targets. Finally, participatory observation was use in the action research (AR) cycles. Several data sources providing triangulation were employed as described in the following section.

3.4.1.2 Interviews

Interviews were used during the primary research as a data source, with several potential forms of interviews available to the researcher. These include informal interviewing, which Bernard (1995) says has a lack of structure and the researcher remembers conversations heard over the course of the day. This requires constant jotting and daily sessions in which the researcher unburden his or her memory to develop field notes. De Walt suggests that the:

> *Researcher follows the lead of the participant but asks occasional questions to focus the topic or to clarify points he/she does not understand…the researcher is not necessarily directing the topics for discussion, but is following, or following up on, points raised by another person during the natural flow of conversation (2011, p.209).*

Informal interviews represented an important means of developing an understanding of people's experiences, views and knowledge. These interviews occurred regularly during the research, proving a rich source of information about the work itself, people's experiences and attitudes.

Semi-structured interviews were also conducted using pre-set open- ended questions, with other questions emerging as the interview progressed *(DiCicco-Bloom and Crabtree 2006, Bryman 2012)*. In total 32 semi-structured interviews were conducted with the questions refined as the research progressed as some themes emerged. The people interviewed included managers, superintendents, supervisors, planners, and project engineers (PEs). Interviews were recorded where permission was gained, for transcription as soon as possible after the interviews. In three instances where respondents were unhappy with the interview being recorded, the interview was transcribed in longhand. The software tool, NVivo used to code and extract information from the semi-structured interviews. Initially the semi-structured interviews using a list of prepared questions had focused on organisational change, with 11 interviews undertaken. However, the focus of questions changed as the primary research uncovered unexpected themes, particularly around the use and implementation of the Critical Path Method (CPM) using the Earned Value Method (EVM). The researcher undertook and subsequently transcribed 21 interviews, on this topic.

3.4.1.3 Documents and artefacts

Bryman (2012) notes that documents can be used and analysed in several ways. One example is meeting minutes. On one level, they may seem to be a factual document, listing participants with actions to be taken and resolved. On another level, they may reveal tensions and disputes between individuals or groups within an organisation. Disagreements may also be suppressed, with the minutes displaying apparent alignment with the organisations norms and expectations. In this way, documents can offer several realities and have “a distinct ontological status”. A broad range of documentation providing secondary data, was collected over the course of the primary research. This consisted of time and motion studies, project variations information (PVI) providing data on 29,000 of delay hours and “lessons learned” collated at the end of 2013. Other documents and artefacts included photographs, primavera schedules and meeting minutes. Primary quantitative data included photos, WWP planning metrics and researcher time and motion study data.

3.4.1.4 Chain of evidence

The second method of demonstrating construct validity is to establish a chain of evidence, allowing a reader to determine how the researcher reached the final research conclusion from the initial questions. Gibbert et al. suggest the use of the following:

Authors are also encouraged to be explicit about how the planned data collection differed from the actual process (e.g., in terms of difficulties, how this impacted result and how such difficulties were contained). Discussion of data analysis procedures includes references to qualitative and quantitative data analysis procedures, descriptions of software packages for analysing qualitative data. (2010, p.713).

The thesis takes the reader through the data collection circumstances, starting at the SC head office in Perth and onto the KGP itself. The thesis describes the forced changed in the research method applied and difficulties encountered and countermeasures in the use of the method chosen; action research (AR).

3.4.2 Reliability

Yin says that the objective of a reliability test is:

To be sure that if a later investigator follows the same procedures as described by an earlier investigator and conducted the same case study all over again, the later investigator would arrive at the same conclusions and findings…one perquisite for allowing the other researcher to repeat the earlier case study is the need to document the procedures followed in the earlier case (2009, p.45)

The research reports on the steps undertaken in the process of implementing the tools. This included the observational research (chapter 4), which identifies the importance in engaging the informal leaders and the most appropriate forums to identify them and the benefits from identifying pre-existing knowledge of lean or lean type approaches in the workforce. The research also developed a tool called Team Work Design (TWD) with a description in chapter 5 of how the tool can be deployed. The AR describes the development of prestart boards, of the weekly work plan (WWP) meetings and the pull planning workshops. The methods, artefacts and guidance for the implementation of the Last Planner LPS developed and the description of the development provides guidance to investigators attempting to implement similar research.

3.5 The Action Research Implementation

3.5.1 Strengths and Limitations of Action Research (AR)

AR was used as it allowed collaborative implementation of the lean approach whilst enabling all parties to iteratively learn from and build on the implementation. There are acknowledged strengths and weaknesses in the AR method. One strength is that AR is a participatory process. But there are perceived weaknesses with the approach. AR is sometimes criticised as being unscientific and has found itself excluded from the forum of organizational scholarly research (Coughlan 2011).

Coghlan and Brannick (2012) note the use of the following to ensure rigour. Firstly, the researcher needs to demonstrate how the multiple cycles were undertaken and how it was shown that this was a true reflection of what happened. Also, one should challenge and test one's assumptions using process and premise reflection. This was achieved by undertaking six distinct cycles where a clear distinction demonstrated between constructing, planning, taking action and evaluation. Qualitative data for analysis including interviews, informal discussions, observation and quantitative data. Quantitative data included metrics produced as the LPS was implemented over the course of the AR cycles. Furthermore, reflection sections were used to reflect on what went well and what had gone badly over the course of each cycle.

Krefting (1991), notes that rigour is demonstrated by credibility which refers to the confidence the researcher has about the findings. Several strategies are proposed, including, prolonged engagement with informants, peer examination and reflexivity. Rigour was demonstrated by prolonged engagement with informants over an 18-month period. Peer examination was achieved through meetings and skype calls with the academic and industry supervisors. Furthermore, the researcher had daily contact with the onsite facilitator (SC 01). He continuously provided feedback, and fact checking, affording technical and historical knowledge about the plant, whilst discussing and critiquing the researcher's perceptions of the workforce culture and ability. Furthermore, the researcher forwarded a weekly report to the industrial supervisor (SC 02), with findings and observations examined. The findings were discussed where factual errors about the plant, process and workforce were identified and findings discussed and critiqued in weekly skype calls. Reflexivity was obtained using a research diary, with contemporaneous observations written in longhand, for transcription later, into a word document. Data was collated from conversations, non-participant observations at early morning prestart site meetings, observation of the workforce as they carried out on site activities, attendance at the pre-start H&S briefings, at planning meetings, at daily pre-start meetings where previous progress on each shift was reported on and the upcoming shifts progress anticipated and discussed. Writing observations involves reworking of field notes to provide meaningful evidence (Jarzabkowski et al., 2014). Therefore, the “hard copy” field notes were completed as soon as possible after each day’s fieldwork. This consisted of two data types. Firstly, the hand-written field notes were transcribed. Secondly, early analysis involved reflections on outcomes where emerging topics were noted at the document’s margin. Reflexivity was also achieved by using memos reflecting on what went well and what went badly.

3.5.2 Collecting Data

Quantitative data was extracted from a broad range of documentation. This included project variation information (PVI), where 29,000 hours of delay data had been collated over a nine-month period. Further documentation included “lessons learned” workshops; productivity norms and a time and motion study of the LNG 2 shutdown, collected during the ongoing refurbishment program between 2012 and 2013. Other documents and artefacts included photographs, primavera schedules and meeting minutes. Primary quantitative data sources included WWP planning data and researcher time and motion studies.

Quantitative and qualitative data was obtained from the AR cycles, which were cyclical and iterative in nature with the outcomes from one cycle informing the development of the plan in the following cycle. The people involved in these cycles included scaffolders, mechanical workers, grit blasters, painters, cladders, Inlecs (instrumentation and electrical workers), inspectors, supervisors, superintendents, managers, planners and project engineers (PEs). Qualitative data was collated from observation, participant observation, conversations, formal and informal meetings was recorded contemporaneously using a research journal. Primary quantitative data was also collated from the implementation of the LPS and secondary data from SC documentation and CPM reporting. Data details including research particulars detailing meetings and workshops (table 4.1), action research participation (table 4.2) and research summary (table 4.3) are tabulated in chapter 4.

3.5.3 Analysing the Data

Khan and Tzortzopoulos (2016) note that whilst AR can be used in evaluating implementation of lean construction, there is still no convention for evaluating outcomes, so lean researchers must develop their own set of criteria. The researcher developed criteria over a period aided by discussions with the academic and industrial supervisors, literature review, and trial and error followed by reflection.

Coding was used to analyse the data collected (figures 3:2, 3:3, 3:4). Coding facilitates the extraction of meaning from the large amount of data collated during primary research. Saldana says a code in qualitative enquiry is:

> *Most often a word or short phrase that symbolically assigns a summative, salient, essence-capturing and/or evocative attribute for a portion of language based or visual data. The data can consist of interview transcripts, participant observation field notes, documents, drawings, artefacts photos….and so on. (Saldana 2013, p.3).*

Miles and Huberman (1994) notes that as soon as information is compiled during the research, challenges appear as information and data build up. Therefore, codes are required for organisation and sense making purposes and these are:

> *Tags and labels for assigning units of meaning to the descriptive or inferential information compiled during a study (Miles and Huberman 1994, p.56)*

Topic coding was used to identify emerging topics, particularly those identified in the research journal. Finally, thematic coding was used to identify emerging themes in the semi-structured interviews (figure 3:4). Quantitative data was collated and analysed for trends using graphs. Data from each cycle was analysed for outcomes and trends using colour coding for the analysis (figure 3:2)

Code		Description
(red)	Improvement required	Improvements required due to a lack of engagement, understanding or training.
(blue)	Some visible improvements/ engagement	Some limited development of good practice demonstrated by engagement by some participants.
(yellow)	Improvement in Practice	Improvements with positive engagement by most of participants including last planner, demonstrated by observation or data.
(green)	Good practice	Engagement by all or almost all participants. Consistent high PPC metrics achieved. Participants on time and engaged in forums including WWP meetings and daily huddles (DH).
(purple)	Evolution in practice	Development of the tools to suit the work environment. Autonomous workforce development of lean approaches or tools.

Figure 3:2: AR Colour Coding

The following coding used in the analysis of AR cycles, with some developed from literature and the rest developed inductively.

Code	Description
Embedment Setback	Instances where the implementation appeared to be failing
Engagement	Instances where people demonstrated positive engagement with the lean tools.
Evolution of Practice	Demonstration of unexpected development of the tools by people interfacing with and utilising the tools
Informal Leaders:	Instances where informal leaders would exert their influence.
Lack of Training	A lack of appropriate training preventing people from performing optimally
Lack of knowledge	A lack of knowledge on an area of expertise such as scheduling
Management Influence	Instances where management exerted influence
Observable impact	Instances where the embedment of a lean tool demonstrated positive outcomes.
Previous lean/lean type experience:	Demonstrations by the workforce and management of previous experience with lean type approaches
Resistance	Explicit and sometimes subtler resistance to the implementation of the tools by the workforce and management
Synchronisation	People interacting and synchronising activities, including arriving on time at DHs, leaders stepping forward, participants offering assistance
Team Autonomy	Observed ability of a team to conceptualise and independently develop the tools, even at some stages developing unexpected variants.
Use of Language	The changes in language use particularly as the tools gained acceptance
SC Support	Support offered by SC management and supervisory teams
Plant Complexity	Complexity of the plant which included many interrelated and complex process

Figure 3:3 AR cycle coding

Sources where data was collected were coded as follows; reflective memo (MEMO), meeting (MEET), daily huddle (DH), Weekly Work Plan meetings (WWP), primary and secondary documentation (DOC), e-mails (e-mail). Codes developed in figure 3:3 were also used in the analysis of the observational findings. The methods and forums uses to gather data were coded as follows observation (OBS), conversations (CON), H&S pre-start (HSP), meeting (MEET), Weekly Work Plan meeting (WWP).

The semi-structured interview comments (COM) were assessed and analysed using the following codes (figure 3:4), developed literature and inductively.

Code	Description
Logic	Evidence of logical plans and schedules
Experience	*Experience levels demonstrated.*
Training	*Training requirements*
Knowledge	*Knowledge levels demonstrated*
Links	*Use of activity links especially the practice where links are removed in a schedule to make it "work"*
Reporting	*Alignment of reporting with "reality"*

Software usefulness	*The relevance and fit for purpose of the Primavera software*
Data	*Data collection methods used*

Figure 3:4-Semi structure interview coding

3.6 Research Ethics

The implementation was informed by Nottingham Trent University ethical research policy. The research could only be undertaken after several safeguards were in place. This included the implementation of a contract, a mutually hold harmless agreement, providing protection to stakeholders including NTU from any actions or repercussions from the research implementation. Furthermore, consent was gained from SC management at the Perth head-office and the KGP, the contractors undertaking work at the KGP. The researcher described the implementation with the participants prior to research start. Furthermore, all participants were anonymised in the thesis and consent was asked from those involved in the semi-structured interviews. Three people refused consent and these interviews were recorded in longhand. Finally, the thesis was reviewed by SP stakeholders, for factual inaccuracies or any information deemed sensitive before release of the thesis for publication.

3.7 Conclusion

A literature search was used to investigate EC, lean construction and its development from flow production, construction project performance and culture. SC documentation was analysed to gain information on factors impacting on performance. The primary research approach was AR using mixed method research with 7 cycles used, investigating outcomes from the implementation of the LPS incorporating TWD. Quantitative secondary data was collected from SC documentation and primary data collected through the AR. The qualitative data collection methods included the use of field notes, questionnaires, semi-structured interviews with quantitative data collected from secondary sources included archival and contemporaneous reports, with primary data collected from semi-structured interviews, time and motion studies and LPS metrics.

4 Enabling the Action Research

Introduction

The primary research was undertaken over an 18-month period on the ongoing refurbishment of the Karratha Gas Plant (KGP) integrated Liquefied Natural Gas (LNG) plant. Action research (AR) was used, investigating distinct refurbishment projects, with lessons from each project informing the construction and planning phase of the subsequent cycle. Observation was also used to explore workforce culture, capabilities and the KGP work environment, with findings informing the implementation of the AR cycles. The research examined the implementation of the Last Planner System (LPS) incorporating a tool developed by the researcher called Team Work Design (TWD). The AR method allowed the researcher to work closely with the workforce in the implementation of the LPS and TWD. Researcher input included the organisation and involvement in the Daily Huddles (DH), Weekly Work Plan (WWP) meetings, pull planning workshops and TWD forums, used to develop continuously improved standard work. Opportunities to observe included interaction at the work fronts, attendance at the prestart health and safety (H&S) meetings, attending Engineering Procurement Construction Management (EPCM), Implementation Contractor (IC) meetings and workshops.

The research design was informed by findings and gaps revealed in the literature. These included the lack of research into issues that impact performance levels encountered in EC projects. Therefore, secondary data was extracted and analysed from existing SC documentation. Furthermore, literature revealed little research on the Australian EC industry workforce and the environment. Therefore, the workforce culture and environment was investigating with the findings informing the AR cycle implementation. Table 4:1 provides information on the AR undertaken over 7 cycles undertaken at the KGP, with details on the participants. The semi structured interviews were carried out with project engineers (PEs), supervisory staff, managers and planners to investigated the use of the Critical Path Method (CPM) of scheduling. Meetings held included formal pre-organised meetings, WWP, DH, TWD and pull planning (PP) forums and more informal meetings/discussions. Meetings attended included start of shift and health & safety prestarts, smart-starts and daily planning meetings. Table 4:2 provides further information on the research participants.

Time Period	Total Time	Project	Tools/ resources used	Comments	Research Method	Data gathering		
						Semi-structured interviews	Meetings held	Meetings attended
Nov-Dec 2013	5 weeks	None	Secondary data including productivity data, time and motion studies and lessons learned workshops.	Visit to Perth HO and Karratha. Making initial contacts and discussion of identified scope.	Desk top study		**30 No meetings** with project managers, planners, heads of department, supervisory staff, continuous improvement staff, estimators, support staff.	
March-April 2014	6 weeks	Shut down targeted inspections (STIPS). Stand alone inspection work.	Daily Huddle (DH), Weekly Work Plan (WWP) and Team Work Design (TWD)	Accelerated schedule. Quick engagement with production planning and DH. Experimental research design proposed research method.	AR Cycle1		**19 No meetings** continuous improvement staff, supervisory staff, planners, H&S staff, QA/QC staff. DH **4** / WWP **2** / TWD **1** / PP **0**	**24 No** Health & Safety prestarts, EPCM early morning prestarts.
May-June 2014	6 weeks	Dom gas 1 shutdown. Difference from cycle 1 with different contractors and refurbishment work undertaken.	DH and WWP	Research method changed to Action Research (AR). Patchy engagement with WWP, good with DH.	AR Cycle 2		**12 No meetings** supervisory staff, planners, H&S staff, PEs. DH **18** / WWP **7** / TWD **0** / PP **0**	**20 No** Health & Safety prestarts, EPCM early morning prestarts.
July-Sept 2014	10 weeks	Domgas 2 shutdown. Similar scope and contractors to previous cycle.	DH, WWP and TWD.	Variable engagement with DH. Improved engagement with WWP. High work variability, demonstrated by variable start times to work days.	AR Cycle 3		**22 No meetings** continuous improvement staff, supervisory staff, planners, H&S staff, QA/QC staff. DH **32** / WWP **12** / TWD **1** / PP **0**	**32 No** Health & Safety prestarts, EPCM early morning prestarts.
Aug-Sept 2014	8 weeks	LNG 1 pre-shut works Similar but larger scope to previous cycle.	DH, WWP and pull planning (PP) workshops.	Engagement with WWP, medium work variability. Evolution of tools evident by workforce.	AR Cycle 4	**12 No** Supervisory staff, planners, project engineers (PE)	**12 No meetings** supervisory staff, planners, H&S staff, WEL management and support staff at KGP and Perth head office. DH **20** / WWP **10** / TWD **0** / PP **1**	**16 No** Health & Safety prestarts, EPCM early morning prestarts.

Time Period	Total Time	Project	Tools/ resources used	Comments	Research Method	Data gathering						
						Semi-structured interviews	Meetings held					Meetings attended
								DH	WWP	TWD	PP	
Oct-Nov 2014	8 weeks	Domgas metering. Scope involved metering works with different contractors to previous cycles	DH, WWP and PP workshops.	Engagement with DH and WWP. Use of integrated DH with pre-start board. WWP, average 80% PPC with 25% productivity improvements	AR Cycle 5	**9 No** Supervisory staff, PEs managers, planners	**14 No meetings** with managers, supervisory staff, planners, H&S, & QA/QC staff and PEs.	**12**	9	**0**	1	**22 No** daily planning meetings,
Jan–March 2015	6 weeks	Jetty refurbishment. Different scope to previous cycles. EPCM contractor not previously involved in research WWP, DH and TWD meetings with inspectors	DH, WWP and TWD.	TWD- first complete implementation of this tool	AR Cycle 6	**4 No** Supervisory staff, PEs	**17 No meetings** managers, supervisory staff, planners, QA/QC staff	20	4	1	0	**12 No** project planning meetings
		Pre-start planning and design for Domgas and pipe refurbishment Pull planning workshops with WEL, EPCM, CI management, support and supervisory staff.	Pull planning	Engagement from projects engineers, project managers and supervisory staff Development of pull planning	AR Cycle 7		**8 No meetings** supervisory staff, management, planners.	0	0	0	2	**12 No** Meetings with PEs planners, supervisory staff, WEL management,

Table 4:1 Research particulars

Code	Position	Experience	Years' experience	Nationality	AR Cycle involvement
IC 01	Painting and cladding field Coordinator	Worked for last 5 years on the KGP with several different EPCM and TPC contractors on refurb. Previously worked on LNG greenfield sites in Australia	5-10	Australian	Cycle 2,3,4,5
IC 02	Mechanical Supervisor	Worked for the last 6 years at KGP with several contractors all involved in the refurbishment scope. Previously worked in oil and gas construction projects throughout Australia	10-20	Australian	Cycle 2,3,4,5
IC 03	Cladding and insulation supervisor	Worked for last 3 years at KGP. Previously worked in oil and gas construction in Australia and the LNG fabrication ship yards in Korea	10-20	Australian	Cycle 1
IC 04	Paint and blast supervisor	Worked at KGP for last 2 years. Has worked in Australia for previous years on greenfield LNG construction projects and some oil construction	10-20	New Zealand	Cycle 1
IC 05	Scaffolding supervisor	Worked at KGP for last 2 years with several contractors. Has worked previously in UK	5-10	European	Cycle 2,3,4.5
IC 06	Paint and blast supervisor	Worked at KGP for the last 5 years. Previously worked in NZ in construction	5-10	New Zealand	Cycle 2,3,4,5
IC 07	Planner	Experience in Australia in LNG and previously in civil engineering	5-10	Australian	Cycle 2,3,4,5, 7
IC 08	Planner	Experience in Australia, started off as a scaffolder and was then a supervisor	20-25	Australian	Cycle 2,3,4,5, 7
IC 09	Scaffolding superintendent	Experience in Australia in the oil and gas industry	10-20	Australian	Cycle 2,3,4,5
IC 10	Welding Supervisor	Experience in Australia in the oil and gas industry	10-20	European	Cycle 2,3,4,5
IC 11	Site manager	Experienced in the Australian oil and gas industry	20-25	Australian	Cycle 2, 3, 4, 6, 7
IC 12	Site manager	Experienced in the Australian oil and gas industry	20-25	Australian	Cycle 2,3,4,6,7
IC 13	Site Manager	Experienced in Australian oil and gas, Worked at KGP for 8 years with several contractors	10-20	Australian	Cycle 2,3,4,5
IC 14	Mechanical Superintendent	Experienced in Australian oil and gas, Worked at KGP for 8 years with several contractors	10-20	Australian	Cycle 5, 6,7
IC 15	Mechanical Superintendent	Worked at KGP for last 7 years. Previously worked in Australia in the oil and gas industry	25-30	Australian	Cycle 6
IC 16	Electrical supervisor	Experienced in the Australian oil and gas industry	10-20	Australian	Cycle 7
IC 17	Mechanical supervisor	Experienced in the Australian oil and gas industry	10-20	Australian	Cycle 7
EPCM 01	Site Manager	Global experience in oil and gas green fields and refurbishment	25-30	Australian	Cycle 1, 2,3,4
EPCM 02	Site Manager	Global experience in oil and gas green fields and refurbishment	25-30	African Continent	Cycle 1,2,3,4
EPCM 03	Planner	Experience in gas and LNG in Australia	20-25	South African	Cycle 2, 3, 4 ,5, 7
EPCM 04	Planner	Experience in Australia	5-10	European	Cycle 2,3,4,5
EPCM 05	Field Coordinator	Worked at KGP for last 5 years. Has previously worked in oil and gas construction projects in Australia and spent 5 years working on construction projects in NZ	10-20	New Zealand	Cycle 1,2
EPCM 06	Scaffolding superintendent	Worked at KGP for last year. Previously worked on LNG Greenfields projects in Australia	10-20	Australian	Cycle 2,3,4,5
EPCM 07	Mechanical Superintendent	Worked at KGP for last 4 years. Previously worked in Australia in LNG and the mining sector	10-20	Australian	Cycle 2,3
EPCM 08	Mechanical Superintendent	Worked at KGP for last 3 years. Previously worked in Australian in LNG and fabrication yards	5-10	Australian	Cycle 7
EPCM 09	Mechanical Superintendent	Worked at KGP for last 5 years. Previously worked in Australian in oil and gas on new build construction	10-20	Australian	Cycle 1,3,4,5,7

Code	Position	Experience	Years' experience	Nationality	AR Cycle involvement
EPCM 10	Inspection site engineer	Experience in lean production with Ford. Has worked at Karratha for the last 4 years with many contractors including Fluor	10-20	Australian	Cycle1, 2, 3, 4, 6,7
EPCM 11	Inspection site engineer	Has worked at Karratha for the last 4 years with several contractors including Fluor previously worked on civil engineering projects	10-20	Australian	Cycle 1, 2, 3, 4, 6,7
EPCM 12	H&S manager	Worked in Australian oil and gas industry, having previously worked as a mechanical superintendent	20-25	Australian	Cycle 1,4
EPCM 13	H&S adviser	Has experience all over Australia in the oil and gas industry including work	20-25	Australian	Cycle 2,3,4,
EPCM 14	Inspector	Experienced in oil and gas in Australia			Cycle 1, 2, 3, 4, 6,7
SC 01	Project Engineer	Worked at KGP for last 12 years. Previously worked in oil and gas construction industry in Australia	25-30	Australian	All cycles
SC 02	Head of construction	Worked at SC for 15 years running mega projects in Australia and globally. Has worked as a manager in the oil and gas industry previously in Australia and globally	25-30	Australian	All cycles
SC 03	Project Engineer	Worked with SC for 12 years and globally previously	25-30	European	Cycle 6, 7
SC 04	Project Engineer	With SC for 14 years, and worked globally previously	25-30	European	Cycle 3,4,5,6
SC 05	Project Engineer	With SC for 8 years, oil and gas global experience	30-35	Australian	Cycle 1,2,3
SC 06	Planning engineer	Global experience mostly in oil, gas and other resources with experience also in heavy structures and infrastructure	25-30	SE Asian	Cycle 2,3,4,6
SC 07	Planning engineer	Global experience in oil and gas	10-15	European	Cycle 2,3,4,6
SC 08	Project lead	Global experience in oil and gas including the middle east	25-30	South African	Cycle 2,3,4,5
SC 09	Construction Superintendent	Global experience including middle east. Has worked as a lead superintendent	25-30	Australian	Cycle 7
SC 10	Construction Superintendent	Global experience including middle east. Has worked as a lead superintendent and a manager	25-30	Australian	Cycle 2,3,4,5
SC 11	Commissioning Superintendent	Global experience in oil and gas	30-35	Australian	Cycle 1,5
SC 12	Supervisor	Worked at KGP for 20 years, previously worked as a mechanical blue- collar worker	30-35	Australian	Cycle 2,3,4,5
SC 13	Supervisor	Worked at KGP for 18 years previously worked in oil and gas	25-30	Australian	Cycle 1,2,3
SC 14	Supervisor	Worked at KGP for 7 years first with EPCM contractor and then client. Previously worked in oil and gas in Australian	25-30	Australian	Cycle 4,5
SC 15	Superintendent	Worked at KGP for 2 years. Experienced in Australian and globally as a superintendent and lead superintendent, has also worked in the mining industry	20-25	Australian	Cycle 1,2,4
SC 16	Operations Superintendent	Worked in KGP for 10 years and in other Australian oil and gas construction contracts	25-30	Australian	Cycle 4,5,6,7
SC 17	Costie (QS)	Worked in the industry for the last 15 years, worked on some of the big schemes including Pluto	15-20	Australian	All cycles
SC 18	Senior Engineer	10 years' experience in the industry. Worked as senior engineer on the EC at KGP and now working in IPT (integrated planning)	15-20	Australian	Cycle 2,3,4,5
SC 19	Projects Co-Ordinator	30 years' experience in the industry. He has worked for a lot of the main oil and gas companies including shell	30-35	European	Cycle 4,5,6
SC 20	Engineering co-ordinator	Started on the tools. Highly experienced in the industry and has also worked in energy in the UK for many years	25-30	Australian	Cycle 2,3,4,5
SC 21	Lead Superintendent	Experienced in oil and gas in Australia including Pluto	20-25	Australian	All cycles

Table 4:2 - AR participants

Research method	Thesis Section	Cycle	Description	Total numbers of participants			Participants (Table 4.2 details)
				IC	EPCM	WEL	
Desk top study, quantitative analysis	Section 4.1.1	n/a	Investigation of performance issues on previous refurbishment projects	0	0	8	SC 01, 02, 03, 04, 06, 17, 21
Action Research	Section 5.1	1	Shut down targeted inspections (STIPS). Stand alone inspection work	2	7	5	**IC**,03,04 **EPCM** 01,02, 05, 09,10, 11, 12, **SC** 01,02 11,13, 15
Action Research	Section 5.2	2	Dom gas 1 shutdown.	11	9	14	**IC** 01,02, 05, 06, 07, 08, 09, 10,11, 12,13 **EPCM** 01, 02, 03, 04, 06, 07, 10, 11, 13 **SC** 01, 02, 05, 06, 07, 08, 10, 12, 13, 15, 17, 18, 20, 21
Action Research	Section 5.3	3	Domgas 2 shutdown.	11	8	12	**IC** 01, 02, 05, 06, 07, 08, 09, 10, 11, 12, 13, **EPCM** 01, 02 ,03, 06,09, 10, 11, 13 **SC** 01, 02, 04, 05, 06, 07,10, 13, 17, 18, 20 ,21
Action Research	Section 5.4	4	LNG 1 pre-shut works	11	10	16	**IC** 01, 02, 05, 06, 07, 08, 09, 10, 11, 12, 13, **EPCM** 01, 02 ,03, 04, 06, 09, 10, 11, 12, 13 **SC** 01, 02, 04, 06, 07, 08, 10, 12, 14, 15, 16, 17, 18, 19, 20, 21
Action Research	Section 5.5	5	Domgas metering.	8	3	13	**IC** 01, 02, 07, 08, 10, 11, 12, 14 **EPCM** 03, 04, 06 **SC** 01, 02, 04, 08, 10, 12, 14, 16, 17, 18, 19, 20, 21
Action Research	Section 5.6	6	Jetty refurbishment.	4	2	9	**IC** 11, 12, 14, 15 **EPCM** 10, 11 **SC** 01, 02, 04, 06, 07, 16, 17, 19, 21
Action Research	Section 5.7	7	Pre-start planning and design for Domgas and pipe refurbishment Pull planning workshops	6	6	10	**IC** 07, 08, 11,12, 16,17 **EPCM** 03, 04, 08, 09, 10,11 **SC** 01, 02, 03, 05, 06, 07, 09, 16, 17, 21
Semi-Structured Interviews	Section 4.1.4	n/a	Investigation of CPM implementation	6	6	9	**IC** 01, 02, 06, 07, 08, 11 **EPCM** 01, 02, 03, 06, 08, 10 **SC** 01, 02, 03, 04, 07, 10, 13, 16, 21

Table 4:3 Research Summary

4.1.1 Exploratory Quantitative Research

The early exploratory study was undertaken in response to a gap in literature indicating little research into wastes experienced in the EC industry. Therefore, a desktop study was undertaken to investigate waste in the production process. This study was undertaken at the SC head office in Perth and at the KGP to investigate the work being undertaken, and issues encountered. The data was collated from previous refurbishment projects at KGP. The documents included time and motion studies, lessons learned workshops and project variation information (PVI) which was over 29,000 hours of delay data collated over a 9-month period on a LNG train refurbishment. This information had been compiled during the execution of a major shutdown of LNG Train 2 (LNG2) executed in 2013. Work included online and offline scope. Online scope is undertaken on live plant and offline during outages. The refurbishment scope consisted of scaffolding, insulation and cladding to piping and vessels, encapsulation and shrouding, blast and paint and mechanical repairs.

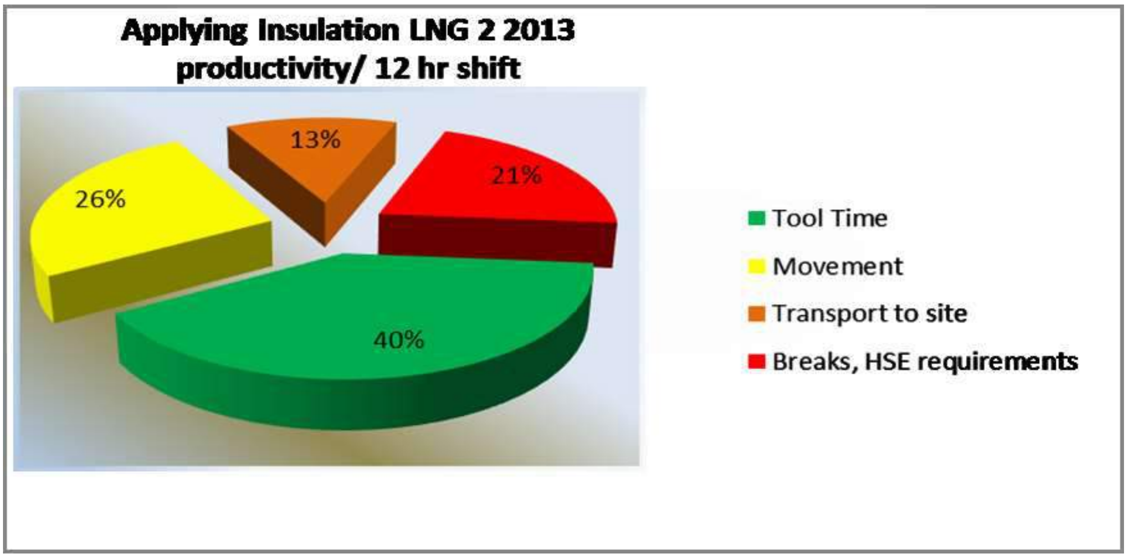

Figure 4:3- Insulation daily breakdown

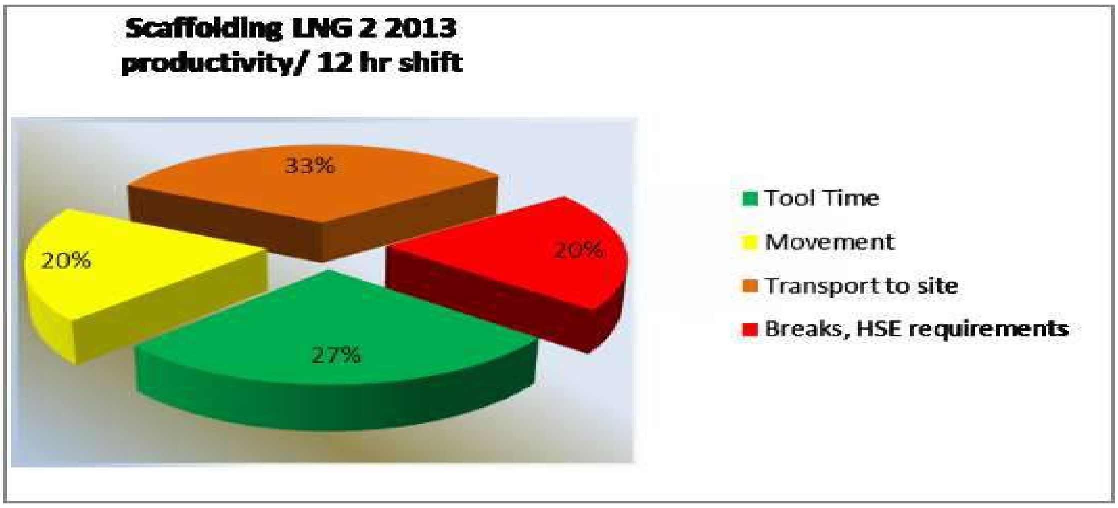

Figure 4:4 – Scaffolding daily breakdown

Analysis of the SC time and motion studies demonstrated the following occurrences of Value Adding (VA) and Non-Value Adding (NVA) activities over the course of a typical working day. VA activities produce what the client requires, which might be a completed and tested weld. NVA activities include the eight wasteful activities, transport, excess inventory, movement, waiting and delays, over production, over processing defects and underutilisation of people potential. The pie charts (figure. 4:3, 4:4) present information on times expended over a typical working day. Tool time is actual time spent at the work face. “Movement” was time spent by workers hunting and gathering tools and materials. “Transport to site” was the time spent travelling to and from work fronts. The researcher analysed the data to reveal information on non-value adding activities. The following are some of the NVA activities revealed.

4.1.1.1 Potential Waste observed

Transportation potential waste (figures 4:3, 4:4) consisted of the time lost in the transportation of work crews from welfare facilities to and from the workface. The distance travelled was 1.5 kilometres each way. Delays were caused by inefficient transportation. Potential lean identified waste also included time lost in organising site transportation and general movement of materials to the work face. Waiting included permitary delays and waiting for work fronts to become available. Data from the PVI documentation was used to populate graphs (figures 4:5, 4:6), providing information on reasons for delay and resulting performance. An analysis of the PVI secondary data (figure 4:5), demonstrated cyclone activity as the main reason for potential waste, followed by planning issues, accounting for 31% of delay. Planning issues was also identified as a cause of delays in the “lessons learned’ report. This information ran counter to the perceived wisdom at the plant; where the perception was that the biggest cause of delay was the development and issue of permits under the integrated safe system of work (ISSOW). The “planning” data is broken to finer granular detail in figure 4:6. This includes workface access (5%), equipment unsuitable (3%) and materials unavailable (4%), conflicting work activities (22%), poor co-ordination (9%), indicated planning issues at the site level, with one of the major issues causing performance was schedule over run (37%), pointed to general planning issues.

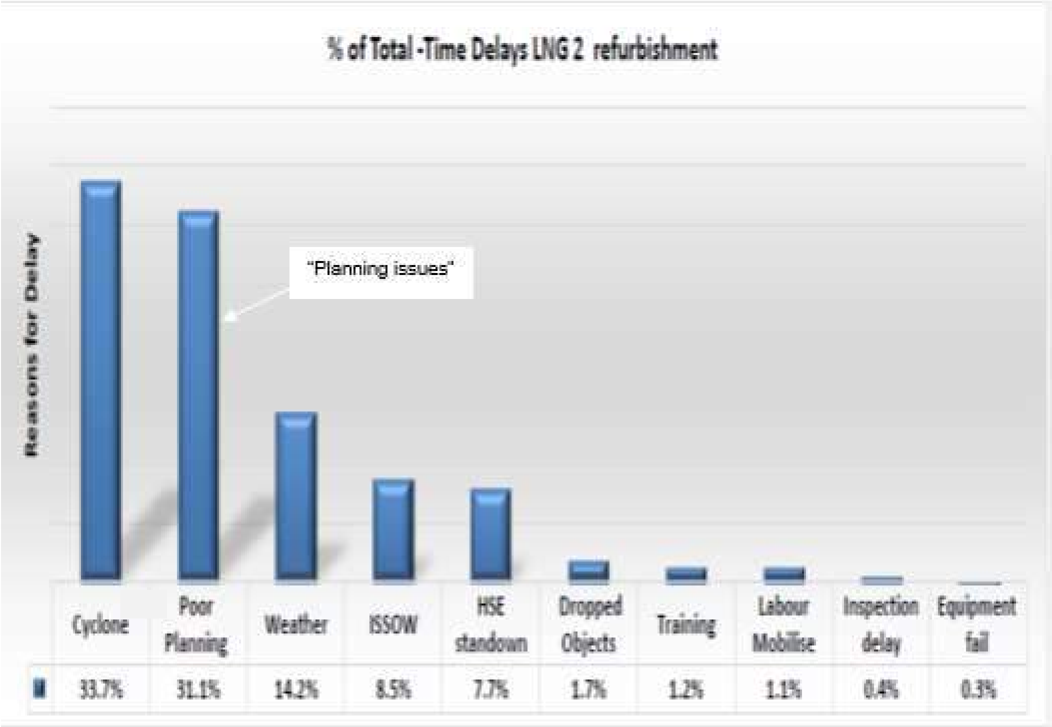

Figure 4:5- Delays over a 9-month period

Figure 4:6- Breakdown of "Planning issues" item from figure 4:5

The most important element of lean construction is waste reduction (Green 1999, Ballard and Howell 2003, Jorgensen and Emmitt 2008, Mao and Zhang 2008, Eriksson 2010), with efficient storage and transportation of parts and materials, referenced as just-in time (JIT) crucial to reduction of waste (Eriksson 2010, Fearne and Fowler 2006). The analysis above highlighted wastes including transportation, movement and waiting in the execution of refurbishment projects at the KGP. Furthermore, all issues revealed in figure 4:6 from "schedule overrun" to "materials unavailable" are ones that can be mitigated by the Last Planner System (LPS), where teams collaborate to develop production planning, with activities only committed to when constraints such as workforce access, equipment and materials unavailability are removed (Ballard and Tommelein 2016, Ballard 2000). Findings from the analysis of data above confirmed LPS as appropriate to counter the issues uncovered.

Following the quantitative analysis, observation and participant observation was used to investigate workforce culture at the KGP, as a literature revealed a paucity of research investigating the Australian engineering construction workforce in terms of culture. The findings from this investigation carried out the 18- month primary research period informed the AR implementation.

4.1.1.2 The KGP Workforce

The KGP plant workforce consists of construction workers, plant operators, management and support staff. Nationalities include Australians, South Africans, New Zealanders, English and some Irish. The majority have worked predominantly in the Australian oil and gas construction industry over their careers (table 4:2). Some have worked globally in several countries including the North Sea in the UK. The workforce includes scaffolders, grit blasters, painters, insulators, cladders, welders, mechanical workers and Inlecs (instrumentation and electrical) workers.

Personnel on the KLE live a peripatetic life operating for the most part on a fly in fly out (FIFO) basis, usually 19 days worked followed by 9-day rest and recreation (R&R) roster. However, some of the permanent workforce including SC and supervisory staff are resident in Karratha. Personnel operate on a back-to-back rotation basis, with two people rotating on the same job. EPCM #1 one of the EPCM contractors, operate with around 40 staff, again on a rotation system, with each role requiring two people to work on a back to back basis. IC#1 is the primary Implementation Contractor (IC) and have approximately 20 management and supervisory staff on site at any one time, with approximately 80 workers including, scaffolders, grit blasters and painters, cladders and insulators on the smaller shutdown and pre-shutdown works. This can rise to 1600 workers in the bigger shutdowns where other companies will also be involved.

The FIFO workforce stay in camps, located in the town of Karratha, which is 25 km from the KGP. The main camp was built to accommodate the workforce on the construction of the Pluto LNG plant. At the height of construction, it provided accommodation for 2400 people. This and other facilities provide a high standard of accommodation, providing individual self-contained rooms for each person, high quality and varied food, gyms, outdoor sports facilities, swimming pools, and two bars. Transport is provided to and from the work site.

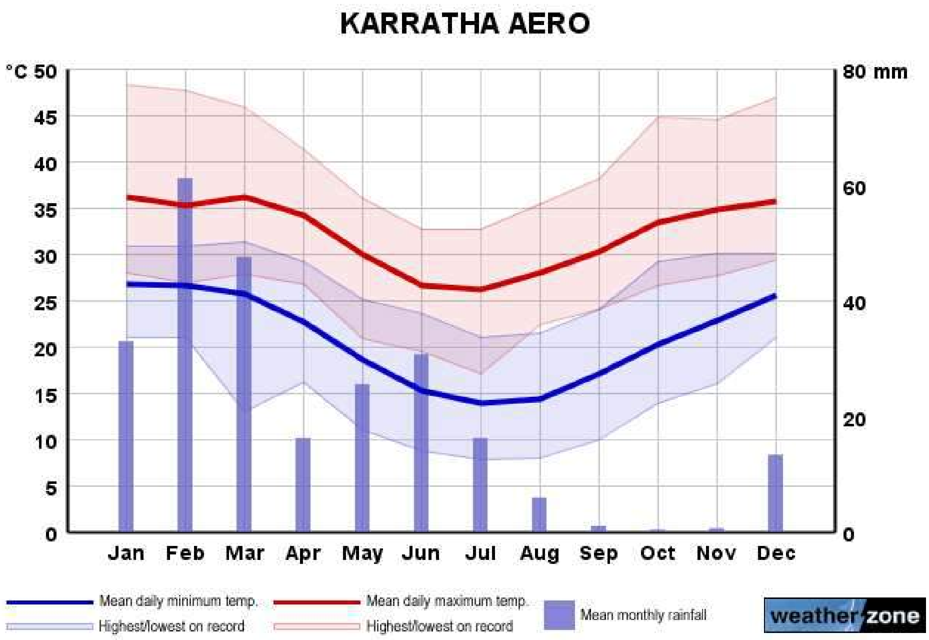

Figure 4:7- Annual Karratha air temperature

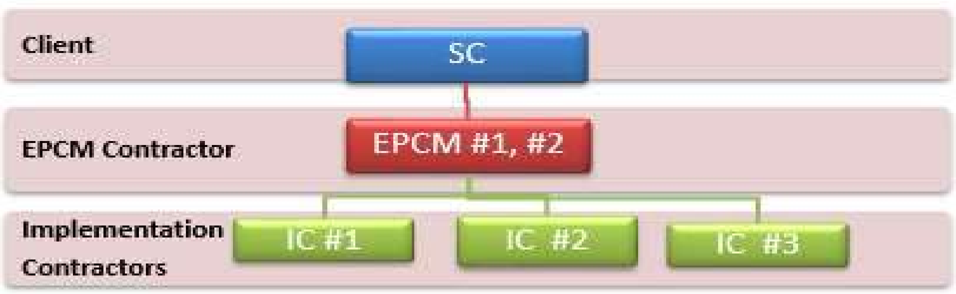

Figure **4:8-** Project Organogram

The organogram (figure 4:8) presents the project management structure following a change management process. This change coincided with the start of the Domgas refurbishment in May 2014. SC previously had a more “hands-on“ role in the design and management of the refurbishment works. It then implemented a planned step back from managing the work directly and appointed EPCM #1 among several other contractors as Engineering, Procurement Construction Management (EPCM) contractors. The SC now act solely in the client role and EPCMs; in turn manage the Implementation

Contractors (IC) as detailed above (figure 4:8). The program of work under this model is badged the Karratha Life Extension (KLE). SC employ approximately 30 people on site on the KLE program. These include planners, superintendents, supervisors and the operators who support the train operation. There are a similar number of designers, project engineers (PE) and support staff working at the head office in Perth supporting the KLE program of work. Working conditions on site are demanding with high summer temperatures experienced, rising to 45°C and above (figure 4:7). The KGP workforce work in a challenging work environment. It is a prerequisite that members of the management team and the workforce have the ability and skill sets to work effectively in this environment. The workforce must also contend with the demands of twelve-hour shifts worked on a six and one basis (six days on with one rest day) on shutdowns and the challenges of the fly in fly out (FIFO) regime. In addition, supervisory staff need good cognitive and mental processing abilities, due to the amount of information and data they are expected to retain and relay as required. The expectation is that supervisory staff and to a lesser extent, the workforce, have an intimate knowledge of the systems within a work area. There is a requirement to have spatial and situational awareness and know the unique reference numbers of the pipework, valves and control systems within that work area. People take pride in their abilities to retain all this information and to be able to navigate confidently through this in their minds and verbalise this mental navigation process. There is also a lot of usage of acronyms, again with an expectation that supervisors and the workers are familiar with these. Those with the ability to present all this and other data and information seamlessly are highly regarded by management. This ability suited people that were relatively confident and extrovert, while those who are of a quieter and more reflective disposition can struggle to make a strong initial impression. Work is carried out on a live plant and this influences the mindset and culture of the workforce. People not only need to be proficient in the competencies described above, but also the presence of different types of risk places added responsibility and pressure on the workforce. The SC uses several strategies to address risk, one of which is the daily prestart H&S meeting followed by the “smart start” communal warm up exercises.

4.1.2 The Prestart Health and Safety meeting

The Health & Safety (H&S) “prestart” is an integral part of the working day and evolved over the period of the primary research. This was a pre-existing forum and attended by workforce and management prior to work staring on each shift. Here, H&S issues pertinent to the upcoming day are discussed, with some discussion on the work to be undertaken over the upcoming shift. The workday always started with the prestart, lasting 20 to 30 minutes followed by the "smart start", which consists of 5 minutes of stretching exercises. The smart start demonstrated how practice has evolved over the years, where the workforce will engage in a practice thought unthinkable some years ago. One experienced the SC superintendent commenting that:

> *10 years ago, people just did the health and safety pre-start and 3 years ago, people started doing warm up exercises. If you had asked him 20 years ago, if Aussie workers would do warm up exercises he would have just laughed at the idea. Then no one thought that the workers would be willing to do warm up exercises and now its accepted practice (SC 11), (CON 1, evolution of practice).*

The prestart has a formalised structure with contractor supervisory staff usually leading it. SC expend time and resources in training the presenters in proper presentation techniques. The early morning prestart are examples of where supervisors and superintendents take control and manage an event with the opportunity for leaders, formal and informal to demonstrate their abilities. The expectation is that the person leading the prestart, with a prepared script is articulate, able to interact with the group to facilitate interaction and feed-back. Many of these events were good, in that there was a demonstration of participant engagement, such as the following example:

> *This was led by IC 02 who was walking among everyone, almost like a stand-up comedian working the audience and seeming to connect with people. This was much more effective than standing at the top of the room. There was some very good feedback and discussion. Theo (ops) told people that the ISSOW software was being updated on the 16th June. This was intended to get rid of redundant lines and make the system a bit simpler to operate. There was good feedback from the welders and suggestions on how danger areas should be segregated from each other, each to have their own warning bunting. IC 04 mentioned that when you have wandered into a wrong area by mistake, you have lost situational awareness, you should then take time out, and do a step back 5 x 5. If necessary, raise a MHR (Minor Hazard Report*), (HSP1, informal leaders).

As discussed, the SC goes to considerable lengths to ensure that supervisory staff receive appropriate training and guidance in effective presentation. The pre-starts varied from being effective and sometimes inspiring, to being long-winded and tedious. IC 05 compared the tedium to that at Sunday religious services in Scotland when he was a young boy. These instances would occur when some managers would take over with a tendency to repeat messages and drag out proceedings, However, other managers would engage effectively with the assembly. The term manager is a specific term, applied to line management above superintendent level. When operating at their best these pre-starts were facilitated by the superintendents and field supervisors with a good deal of interaction between the groups with information pertinent to the upcoming day's work being exchanged. The following example is an intervention by one of the SC's managers at another of the early prestarts.

> *SC 05 is now working as a SC project engineer but has worked his way up the ranks having started out as mechanical worker like a lot of those present. He said that the reason he had stood up this morning was that he noticed that some of the mechanical fitters were working in oily overalls and not changing them when they became dirty and oily. SC 05 remarked that he used do the same with the result that he now has skin problems resulting in discolouration of his arms and legs. He rolled up his sleeves to show very red skin irritation. He said that he had the same problems with his legs. He can never get rid of this dermatological condition, which came about because of lack of care when younger. The room went silent for 10 to 20 seconds afterwards, especially among the mechanical workers, some of whom were wearing oily overalls,* (*HSP* 2: informal leaders).

The following is an example of a prestart by an informal leader, a person, who at a later stage led the implementation of the LPS.

> *Prestart by IC 01 @ 7:00 am. Follow up by EPCM 12 (H&S manager)*
>
> *Good interaction from IC 01. Did anyone go fishing on their day off?*
>
> *Warned that it was going to be hot at Domgas especially with the light wind today*
>
> *He asked if there were any issues with Domgas; there were none from the operators.*
>
> *EPCM 12 asked questions on the daily topic, which is hose management and some feedback on what the main points to look out for are and asked for some personal experiences from the assembly.*

A worker: A few years ago, he was on a job (not for the SC) where there was no whip check on the hose connectors when a worker was carrying out some grit blasting. The connection failed and split hitting the operative and killing him.

Another Story: a young lad was blasting and painting and hooked up to the wrong line (nitrogen) and was badly injured, requiring hospital treatment.

It was apparent that these stories had a sobering effect on the assembled. (HSP 3: informal leaders).

There were numerous examples of informal leaders demonstrating their skills by encouraging people to relate powerful stories, which always seemed to have a marked effect on people listening. This marked effect was demonstrated by the silence of the assembled after the narrative being told. In many cases, informal leaders would tell stories or encourage other people to relate personal experiences. The Implementation contractor (IC) and Engineering Procurement Contract Management (EPCM) supervisory staff would also use the prestart as a forum to challenge both the workforce and management alike. The following is an example of where this type of event occurred.

IC 01 got everyone to stand who had their HSE (health, safety and environmental) handbook with them. About 70% stood up. The he asked everyone to sit down that hadn't the current rev 9. About 30% were left standing. He then asked the people standing to go to page 81 and each person had to read out a bullet point before they could sit. There was discussion and banter on some of these points and was a good way to get the information out (HSP 4: informal leaders).

This type of occurrence happened frequently, demonstrating that members of the IC supervisory staff were quite willing to challenge and hold people to account, including the researcher, no matter what level and which organisation they represented. It seemed an egalitarian attitude, where the same standards and expectations should be applied to all. It became evident over the course of the primary research that the people who stepped forward in the prestart meetings were the same people who would instigate change, leading and mentoring the implementation of the lean tools. The nature of the prestart changed over the course of the research, due to SC initiatives. These are discussed, particularly where they had a direct influence on the research implementation. The next section discussed a characteristic of the work environment, which was types and consequence of risk.

4.1.3 Risk and its consequence

Introduction

The work environment is a high-risk one. There are H&S risks for the workforce and process risk to the plant itself. The plant is noisy and hot, adding to the existing Karratha high air temperatures. This can make for a difficult, stressful working environment taking a mental and physical toll on the workforce.

The SC states that H&S is a key consideration and takes precedence over all aspects of the refurbishment work. The company lists the hierarchy of factors in undertaking the refurbishment work. The first requirement is that work is carried out safely, the next that it is carried out to the necessary quality standards and the last that it is completed to schedule and cost. There are several reasons described below for the high priority given to H&S.

Health and safety risks

There are two distinct types of risks present during the execution of the refurbishment work. These are H&S and process risk. H&S risk (figure 4:10) includes immediate risks from working at heights, from slips, trips and falls, line of fire and so on. There are also risks due to hazardous materials and dangerous environments of the plant. These includes cyclical heating and freezing of pipe work, where pipes are energised at intervals during the day, the presence of high-pressure air-lines and risk to personnel presented by possible loss of containment (LOC).

Figure 4:9- Process trip points

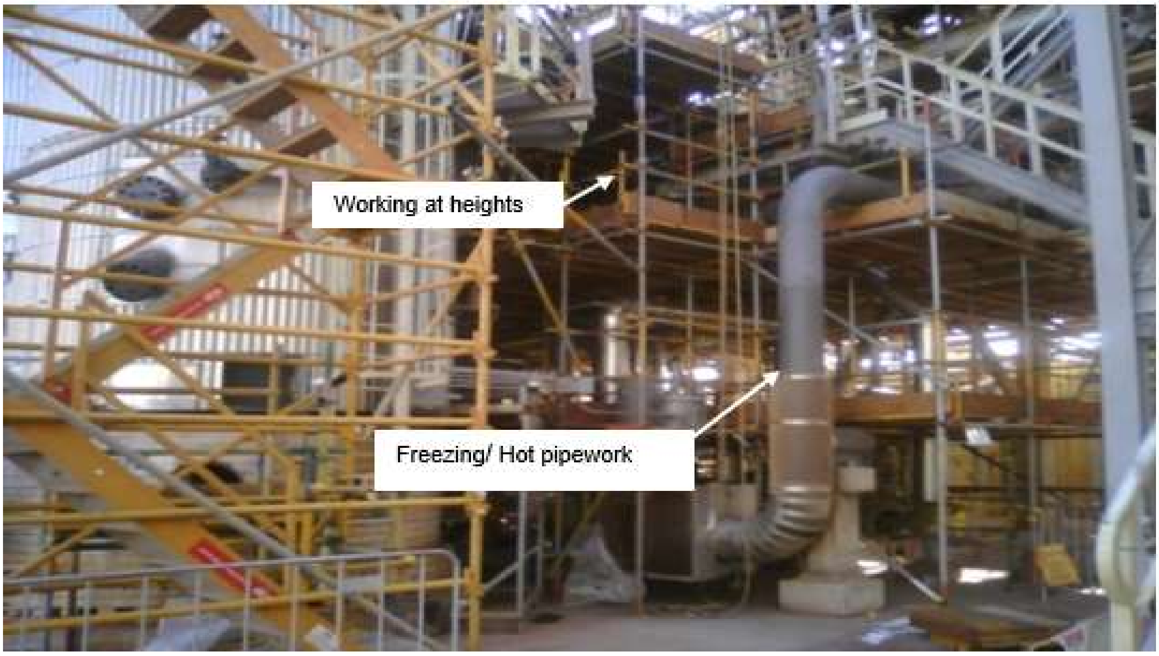

Figure 4:10 Health & Safety Risk

Process failure outcomes are potentially costlier and more catastrophic than health and safety ones. Examples of process failure are the Piper Alpha disaster in the North Sea in 1988 and the BP Deep-Water Horizon oil spill in the Gulf of Mexico, which lasted from the 20th April 2010 to final sealing on the 15th July 2010. To mitigate against process risk, trains or other process will shut down automatically if anomalies are detected. There are numerous points (figure 4:9) on the plant that can cause the plant to trip. These are identified where possible with red ribbon. These small-bore pipework, instrument airlines, switches, gauges and levers can cause a train trip if interfered with.

The operator's role, demands experience and knowledge. Each trip may have a unique cause and finding a solution to restart demands a comprehensive understanding of how the whole system works and operates. There is a high monetary cost, as a result lost revenue/train/day. It is highly stressful for the operators and there is the potential of harm to personnel. All personnel must vacate the site to safe muster points following a plant trip.

Consequently, there is a constant awareness among personnel of the ever presence spectre of a trip, the possible trip points and the consequence of each trip. SC as an owner operator, aware of the risks and potentials for harm have put in place the following procedures over many years, described below.

4.1.3.1 Mitigation of existing risk

There are several methods used to reduce the risks encountered daily from potential hazards during the operation and reconstruction of the plant. The risks are reduced to a point which is as low as reasonably practicable (ALARP) using some of the following systems.

Integrated Safe System of Work (ISSOW)

To mitigate the risks described above SC have a system of checks and controls called the integrated safe system of work (ISSOW). The ISSOW is a complex system using a permit to work (PTW) and a colour coded lock process to ensure that process plant is safely isolated before any work is carried out. Figure 4:11 details a small section of an ISSOW flowcharting developed for a relatively simple scope of work. The development of this requires a great deal of input from the operating staff, management and supervision to build up a robust schematic detailing a particular isolation, control and deisolation process for a particular activity, that is safe, workable and practicable. Still, it has now been recognised that in trying to cover all eventualities, the system has become overly complex and burdensome, impeding workflow unnecessarily. Currently the process is undergoing some simplification and rationalisation.

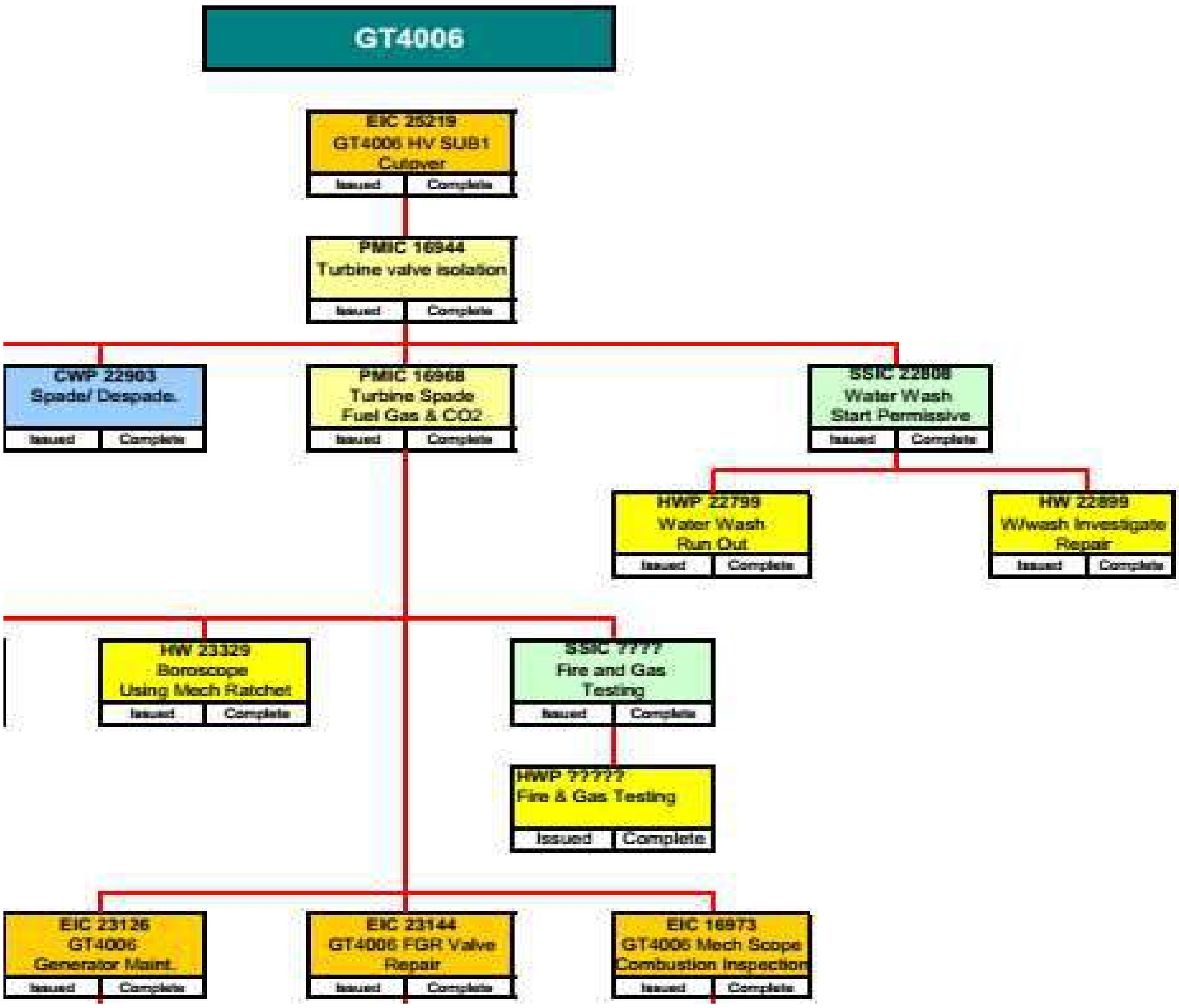

Figure 4:11- ISSOW flowchart section

The ISSOW process (figure 4:11) is used in the work planning and execution. The design phase of any work scope involves input from the plant operators, to determine potential repercussions of particular actions and process. The operators know the plant intimately and can determine where and in what sequence the isolations need to be in place before a system can be quarantined, how the isolations are to be maintained during the refurbishment works and how and in what sequence the isolations are removed as work is completed. This is extremely complex work, where mistakes can lead to potentially catastrophic outcomes. There is an onus not just on the operators to get their planning and control systems right, but on everyone involved, including designers, managers, supervision and the workforce to have an appropriate understanding of the systems, the processes and the potential hazard and risks. This necessitates that personnel working at the plant have good cognitive processing abilities, superior data retention ability and communication skills. The management, supervision and the workforce work with an awareness of the potential for harm from two risk types as discussed, putting added pressure on people who are already undertaking demanding and complicated work tasks.

The Critical Path Method (CPM) project planning provide milestones for the LPS production planning, with issues soon uncovered with its use particularly as it interacted with the use of the LPS. Therefore, investigation of its use was undertaken with the following section describes the investigation and analysis.

4.1.4 The CPM planning method

The early findings from observing the interaction of the flow LPS, traditional construction, and the cost focused CPM planning approach confirmed issues with the use of CPM /EVM software, in particular the industry standard, Primavera®. Initially the literature review had uncovered criticisms of the CPM planning approach, confirmed by the early research implementation. The following discussed the actual effectiveness of the tool and then goes on to examine reasons for this effectiveness or lack thereof.

One of the issues investigated was the quality of reporting by an analysis of twice-daily quantitative data produced from shutdown schedule reporting. Shutdown projects are the fruit flies of construction, progressing at much faster rate than normal construction projects. This feature enables quick

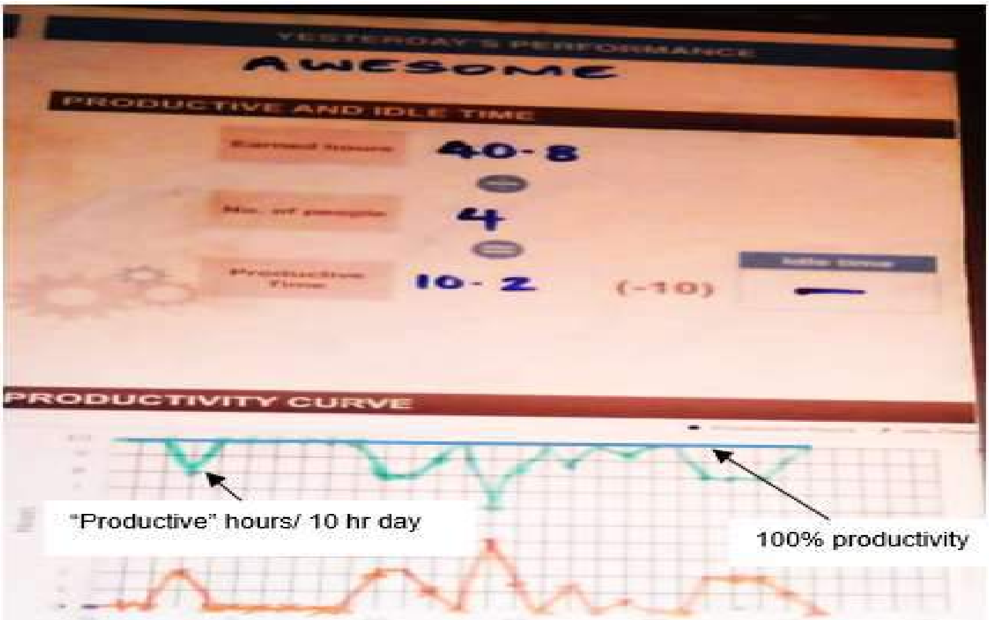

Figure 4:12- EV variance DG 2 (*DOC 15: reporting)*

identification of trends where a large quantity of data could be collected daily for analysis by graphs as illustrated in figure 4:13. The graphs track the variations in the critical path on the Domgas 2 (DG2) shut down over a 14-day period.

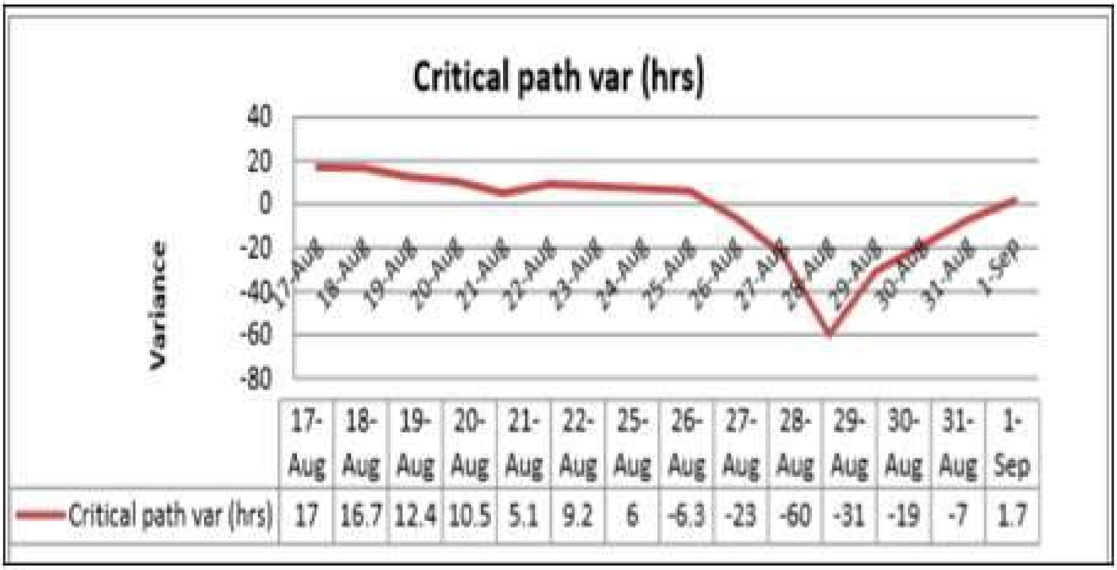

Figure 4:13- Analysis variance DG 2 (*DOC 16: reporting)*

Analysis of the critical path variance in cycle 3 on DG 2 shutdown produced wildly fluctuating variances. At one point the CPM reported the progress as 60 hours (2½ days) behind schedule on a 14-day shutdown. However, the shutdown eventually completed 2 hours ahead of schedule. This disconnection between Primavera® reporting and actual progress on the ground was also observed in other shutdowns. The Domgas 2 scope was not overly complex, but it was apparent to the researcher and the supervisory staff that reporting was potentially inaccurate. Misalignment between reporting and reality was a common occurrence across the refurbishment projects particularly, in the more complex shutdowns. A demonstration of the misalignment was the daily reporting (figure 4:12) produced by the scaffolding supervisors as part of a consultant led productivity improvement initiative on going at the plant concurrently with the primary research. Other trades carried out similar exercises whilst working on the same online refurbishment scope. This graph tracks daily performance using the CPM Earned Value (EV) data achieved by individual trades. The planned value (PV) reporting validates high productivity levels, averaging at 80%, with some productivity at 100%. However, contemporaneous SC time and motion studies on a cross section of trade activates, demonstrated tool time varying between 30% and 60%, with none as high as 80%. In addition, the researcher carried out time and motions studies where the following pie chart (figure 4:14) provides a breakdown of productive and non-productive hours recorded on scaffolding operations.

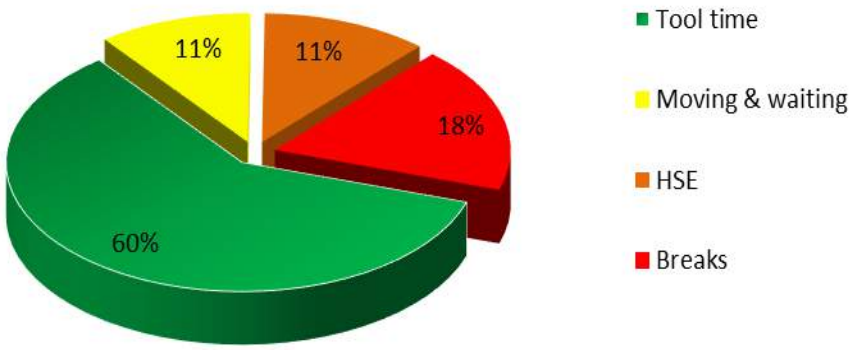

Figure 4:14 DG2 Refurbishment scaffolding productivity

This misalignment between the reported and actual was a further demonstration of flawed CPM/EVM reporting. The quantitative data analysis brought the veracity of the CPM reporting into question. Still, the quantitative analysis alone did not identify the reasons for the observed anomalies. To uncover these, several further data collecting methods were used which included, observation at planning forums, at meetings, site activities, informal discussions and finally semi- structured interviews.

A thematic analysis of 21 semi-structured interviews using NVivo software, and the research diaries revealed several themes. The graphs (figures 4:12, 4:13) demonstrate a striking misalignment between CPM reporting and the reality on the workface. The researcher investigated reasons using the methods described. Several themes emerged, discussed below.

Planners expertise and practice

The execution of refurbishment scope was planned used the EVM producing highly complex schedules with activities planned in some cases, to the nearest hour. Estimators use norms or time estimates allocated time to each activity. These norms have been developed from several sources including the North Sea. Yet, previous extensive research and analysis undertaken by the SC demonstrated large norms variations and inaccuracies. Nonetheless, these norms were still used to inform the early stage of the plan development. Consequently, early planning accuracy was compromised by poor quality input data, making project planning challenging for planners.

Firstly, the research investigated what made a good planner. Several project engineers stated that a good planner needed to have had previous field experience, to develop an understanding of actual timings and the inter-relationships between activities and not simple familiarity with planning software. The themes emerging were that planners needed site experience to develop an understanding of times required for activities and the intricacies and logic of the actual workflow before moving on to a planning role.

The researcher then investigated how the perceived lack of appropriate experience was manifest. The analysis demonstrated difficulties planners had in developing schedules incorporated flow and logic. This area concerned many of the respondents with nine comments on the subject from seven people. SC 10 commented that:

> *If the critical path keeps changing there must be problems with the logic, the critical path fluctuations on DG1 and 2 demonstrated that there was something wrong with the logic. You shouldn't be 60 hours behind the schedule and then come in ahead of schedule at the end (COM 3: logic).*

Furthermore, IC 08 a planner, who has started on site as a scaffolder and worked his way up to a planning role, said that:

> *The links on their (*the EPCM contractor) *don't look logical. People using job cards to form the schedule, just link anything to form the schedule. The same happened on LNG 1 where they were planning for over a year and they ended up doing the same thing. I use the KISS method – keep it simple: stupid (COM 7: links, logic).*

The comments above were representative of a widespread belief held across the KLE organisation that whilst site based experience was a prerequisite for planners to develop competency in the "art of planning", few planners could demonstrate such experience and therefore struggled to develop clear logical plans and schedules. The next section examines other barriers.

Quality and relevance of data:

The schedules developed are highly complex (figure 4:16) with a high degree of sub-optimisation, with activities planned to 0.7 of an hour in some cases (figure 4:15). This is a cost and efficiency approach with costs initially built up by estimators using questionable industry norms. This implicit theory is described as management by results (MBR) which depends on the collation and analysis of a large amount of accurate data to function (Kim and Ballard 2010, Johnson and Brooms 2000). However, as noted researcher data analysis demonstrated misalignment of reporting with actual progress.

Activity ID	Activity Name	Remaining Duration (hrs)	Physical % Compl.	Start	Finish	Budgeted Labor hrs	Earned Labor hrs
JCE001-A-0020R1	Install cable tray / supports internal to Cabinet below new gland plate (MFC 002)	0.0	100%	15-Oct-14 A	15-Oct-14 A	17.0	17.0
JCE001-A-0050	Install Cable ladder between MFC2 & 27MFC001	0.0	100%	15-Oct-14 A	15-Oct-14 A	12.8	12.8
JCE001-A-0060	Cut MFC2 roof to accomodate new Gland Plate	0.0	100%	15-Oct-14 A	15-Oct-14 A	2.8	2.8
JCE001-A-0030	Confirm & Lock onto existing Isolations (Power)	0.0	100%	15-Oct-14 A	15-Oct-14 A	2.1	2.1
JCE001-A-0010	Install & Terminate 35mm2 earth cable to MFC001	0.0	100%	17-Oct-14 A	17-Oct-14 A	4.3	4.3
JCE001-A-0070	Jobcard Closeout	0.0	100%		17-Oct-14 A	0.0	0.0
JCJ001 - INSTALL & TERMINATE CABLES BETWEEN MFC001 & MFC002		20.0		15-Oct-14 A	12-Nov-14	115.0	102.0
JCJ001-A-0050	Install new DIN rail in MFC002 Panel	0.0	100%	15-Oct-14 A	17-Oct-14 A	12.8	12.8
JCJ001-A-0070	Install Surge Protectors 377-12V in MFC002 Panel	0.0	100%	15-Oct-14 A	17-Oct-14 A	8.5	8.5
JCJ001-A-0080	Install Terminals in MFC002 Panel	0.0	100%	15-Oct-14 A	17-Oct-14 A	12.8	12.8
JCJ001-A-0030	Install 7 Off 1.5mm2 x 16 pair cables MFC001 + MFC002 Panels	14.2	93%	17-Oct-14 A	12-Nov-14	42.6	38.6
JCJ001-A-0040	Install 5 Off 0.5mm2 x 04 pair cables in MFC001 + MFC002 Panels	7.1	85%	17-Oct-14 A	11-Nov-14	21.3	17.4
JCJ001-A-0060	Install 80 x 80 PVC Duct in MFC002 Panel	0.0	100%	17-Oct-14 A	24-Oct-14 A	8.5	8.5
JCJ001-A-0090	Install Markers to DIN rails in MFC002 Panel	2.8	40%	17-Oct-14 A	11-Nov-14	8.5	3.4
JCJ001-A-0100	Jobcard Closeout	0.0	0%		12-Nov-14	0.0	0.0
WORKPACK WPJ001 - CLOSEOUT		20.0		13-Nov-14	14-Nov-14	20.0	0.0
WPJ001-9-0010	Workpack Closeout	20.0	0%	13-Nov-14	14-Nov-14	20.0	0.0
WORKPACK WPJ008 - FIBRE OPTIC INFRASTRUCTURE INSTALLATION WORKS (THIRD PARTY)		82.5		18-Oct-14 A	19-Nov-14	185.3	37.4
JCJ013 - INSTALLATION OF COMMUNICATION INFRASTRUCTURE (CABLE LOGIC SCOPE)		19.7		18-Oct-14 A	12-Nov-14	75.8	25.3
JCJ013-A-0100	Arrange Outage with WEL for FAR17 & TECH Office Cable 61-TC-528 terminations	0.0	100%	18-Oct-14 A	20-Oct-14 A	0.0	0.0
JCJ013-A-0030	Serial link Installation -TECH Office	12.0	40%	20-Oct-14 A	12-Nov-14	24.0	9.6
JCJ013-A-0050	Perform Isolation (Instrumentation - 24V) - TECH Office	0.0	100%	20-Oct-14 A	20-Oct-14 A	1.4	1.4
JCJ013-A-0010	Serial link Installation - FAR4	8.0	80%	22-Oct-14 A	11-Nov-14	16.0	12.8
JCJ013-A-0060	Perform Isolation (Instrumentation - 24V) - FAR4	0.0	100%	22-Oct-14 A	22-Oct-14 A	1.4	1.4
JCJ013-A-0080	Perform Isolation (Instrumentation 24V) - CCR	0.7	0%	11-Nov-14	11-Nov-14	1.4	0.0
JCJ013-A-0020	Serial link Installation - CCR	4.0	0%	11-Nov-14	12-Nov-14	8.0	0.0
JCJ013-A-0090	Perform Isolation (Instrumentation - 24V) - FAR17	0.7	0%	12-Nov-14	12-Nov-14	1.4	0.0
JCJ013-A-0040	Serial link Installation - FAR17	7.0	0%	12-Nov-14	12-Nov-14	14.0	0.0
JCJ013-A-0070	Jobcard Closeout	4.0	0%	12-Nov-14	12-Nov-14	8.0	0.0
JCJ033 - INSTALLATION OF COMMUNICATION INFRASTRUCTURE (OWNER SCOPE)		64.5		27-Oct-14 A	17-Nov-14	89.5	12.1
JCJ033-A-0020	Serial link Installation - FAR4 for DBNGP & BEP	14.2	80%	27-Oct-14 A	12-Nov-14	14.2	11.4
JCJ033-A-0100	Perform Isolation (Instrumentation - 24V) - FAR4 Serial Link	0.0	100%	27-Oct-14 A	27-Oct-14 A	0.7	0.7
JCJ033-A-0120	Perform Isolation (Instrumentation - 24V) - CCR PCAD	0.7	0%	12-Nov-14	13-Nov-14	1.4	0.0
JCJ033-A-0060	PCAD Primary & Secondary Installation - CCR for BEP & DBNGP	14.2	0%	13-Nov-14	14-Nov-14	28.4	0.0
JCJ033-A-0080	Perform Isolation (Instrumentation - 24V) - TECH Offices Serial Link	0.7	0%	14-Nov-14	14-Nov-14	0.7	0.0
JCJ033-A-0110	Perform Isolation (Instrumentation - 24V) - BB281 PCAD	0.7	0%	14-Nov-14	14-Nov-14	0.7	0.0

Scheduling to 0.7 hours

Figure 4:15 -Domgas metering scheduling

Activity Name	Start	Finish	Original Duration	Physical % Complete	Budgeted Labor Units	Actual Labor Units
G11-200-00WP-06-JC007 - 2P23002 - CVI-000319 - (11m)*	21-Mar-14	22-Mar-14	10.0	0%	0	0
G11-200-00WP-06-JC009 - 2P23003 - CVI-000322 - (5m x 90mm) 3	02-Mar-14 A	23-Mar-14	27.0	65%	54	35
G11-200-00WP-06-JC012 - 2P23004 - CVI-000325 - (6m x 40mm) 7	08-Mar-14 A	25-Mar-14	55.0	65%	110	72
G11-200-00WP-06-JC013 - 2P23004 - CVI-000326 - (5m x 90mm) 10	10-Feb-14 A	16-Mar-14	27.0	30%	54	16
G11-200-00WP-06-JC016 - 2P23005 - CVI-000329 - (6m x 40mm) 17	10-Feb-14 A	18-Mar-14	55.0	60%	110	66
G11-200-00WP-06-JC017 - 2P23005 - CVI-000330 - (5m x 90mm) 18	03-Mar-14 A	18-Mar-14	26.0	80%	54	43
G11-200-00WP-06-JC019 - 2P23030 - CVI-000333 - (8m x 80mm) 29	11-Feb-14 A	19-Mar-14	32.5	60%	65	39
G11-200-00WP-06-JC021 - 2P23031 - CVI-000335 - (8m x80mm) 31?	11-Feb-14 A	21-Mar-14	68.0	75%	68	51
G11-200-00WP-06-JC022 - 2P23031 - CVI-000336 - (4m x 80mm) 32 / 33	12-Feb-14 A	21-Mar-14	17.0	65%	34	22
G11-200-00WP-06-JC024 - 2P23006 - CVI-000341 - (3m)*	25-Mar-14	25-Mar-14	0.0	0%	0	0
G11-200-00WP-06-JC027 - 2P23007 - CVI-000344 - (3m)*	25-Mar-14	25-Mar-14	0.0	0%	0	0
G11-200-00WP-06-JC030 - 2P23008 - CVI-000347 - (3m)*	25-Mar-14	25-Mar-14	0.0	0%	0	0
G11-200-00WP-06-JC036 - 2F44408 - CVI-000353*	25-Mar-14	25-Mar-14	0.0	0%	0	0
G11-200-00WP-06-JC039 - 2P23009 - CVI-000356 - (15m)*	25-Mar-14	25-Mar-14	0.0	0%	0	0
G11-200-00WP-06-JC045 - 2P23026 - CVI-000362 - (6m x 80mm) 24	12-Feb-14 A	07-Apr-14	59.0	58%	118	68
G11-200-00WP-06-JC048 - 2P23032 - CVI-000365 - (18m x 80mm)	14-Mar-14 A	11-Apr-14	78.0	45%	156	70
PR-21	13-Feb-14 A	24-Mar-14	480.0		480	288
1 C Area 21 Inspections Scaffolding Erect	13-Feb-14 A	16-Mar-14	100.0	90%	320	288
1 C Area 21 Inspections Scaffolding Strip	16-Mar-14	24-Mar-14	100.0	0%	160	0

Figure 4:16 - EVM schedule demonstrating cost focus

The research examined the methods used to collect data and the effectiveness of these methods. Supervisory staff collected data three times daily using short interval control (SIC) sheets, which inform the EVM. Thematic analysis produced 9 references from 6 sources demonstrated widespread scepticism at the quality and accuracy of data collected. Additionally, the time pressure created by data collecting was noted. IC 01 noted:

> *They just want the data, it's probably overly complicated for what it needs to be. A supervisor will be out there in the field, reporting on 14 and 15 different line items and charging hours (COM 8: data).*

EPCM 02 expanded on this sentiment later saying that:

> *You're wasting supervisors' time chasing time sheets and putting hours to activities. The biggest problem is when you don't have an activity id to report against. You do the work but have nothing to report against (COM 9: data).*

SC 01 remarked that:

> *as you said, reporting, it's a lagging indicator, its hindsight, (COM 10: data).*

One of the experienced SC project engineers SC 03 said that:

> *The reporting sometimes is unreliable. It's one of those things, it shouldn't be. If you have the right people on the job, it's not, (COM 11: data).*

The next section describes strategy used by planners to deal with the challenges described.

Delinking and flow of activities

Observation revealed a practice, which was the delinking of certain critical path activities. Analysis of the semi-structured interviews showed 5 references from 4 interviews on the subject. The evidence of delinking was a surprising revelation, as links are critical to maintaining CPM programming functionality. Some reasons for delinking included the need to deal with the occurrence of late activity requests (LARs) which was extra work introduced during the execution of a project. The introduction of LARs could cause the schedule to go super-critical, with actual completion later than planned. Schedule complexity and poor logic described earlier meant that delinking was the only method available to "demonstrate" completion by the planned date. The use of delinking as a strategy to manipulate schedules was confirmed by SC 04, a highly experienced SC project engineer. A senior SC manager SC 08 also confirmed that:

> *This is how they (*the planners) *work it by not linking all activities (COM 12: links)*

SC 10 also noted:

> *That they (the planners) don't link all the activities, but they must have some links because they work out the critical path. …there is a critical path for the shutdown but it changes every day, (COM 13: links).*

IC 06 noted that:

> *At one point in the LNG 1 shutdown, they were 12% behind schedule. This may be because some of the activities aren't linked and scope is being switched between contractors, (COM 14: links.)*

SC 03 also confirmed that activities were being delinked saying:

> *The planners will delink to stop schedules going super critical, (COM 15: links).*

The revelation of the practice of the delinking of activities in schedules was a surprising one as the CPM demands continuous end-to-end linking for the software algorithms to function properly. The removal of links results in the production of inaccurate and skewed scheduling.

The discussion above, examined planner experience levels issues and how barriers inherent in the CPM/EVM approach were overcome. Following on, the ability of the supervisory and management staff to use the actual schedules produced by the software was investigated.

Supervisory Staff Planning knowledge

The research including the AR research in chapter 5 revealed the problems many supervisory staff had in understanding the one to two weeks look ahead "Gantt charts" produced by planners. The semi-structured interviews were used to investigate the matter further. There was a consensus, where interviewees demonstrated strong opinions on supervisors' lack of understanding of CPM schedules produced. Ten interviews produced 18 references on the topic including EPCM 02 expressing the view that:

> *90% of the guys if you stuck a plan in front of them and asked them where they were, they wouldn't have a clue. It's very difficult to pick up detail from the plan if you don't know*

what you are looking at. I understand why it's in there which is for norms and processing, I understand all of that, but your normal everyday guy out on the field, you give that to him and he's lost. You ask him a question about that and he's really stressed. So, the Last Planner was something that they'd created through their supervision who had got involved in it and they were a lot more comfortable with working with it and having the last planner sheet in their back pocket and working to that, (COM 16: knowledge).

One of the EPCM managers (EPCM 01) closely involved in the implementation of the lean tools proposed the following reasons for the lack of understanding saying:

A lot of the supervisors aren't educated enough to do these sorts of things because a lot of them have come up from the tools. They need him (EPCM 01) *or someone of the same stature to tell them what they need to do. This takes up a lot of his resources and energy. He can't just give them a plan and tell them to follow that plan and come back to him if there is any problem with the logic. It's not just this company he's seen this but with all the companies. You look at them all, some struggle to consistently follow a plan, (COM 17: knowledge, training).*

Experienced SC supervisors and management echoed this view with SC 13 noting that:

Some supervisors don't seem to understand that as they go through the job activities how to progress the activities…. I don't know if we need to give them some planning and scheduling training, (COM 18: training).

A SC project engineer SC 03 when talking about this issue pointed to labour force turn over, acting against planning proficiency and understanding:

If you are calling in big numbers and you have only work for a month, then you get what you get … (COM 19: training, knowledge).

The above revealed a previously under researched aspect, which was the ability of supervisory staff to understand, interpret and implement scheduling. The supervisory staff for the most part did not understand schedules produced and so were unable to use schedules to guide workflow. In this way, a vital link in the planning to implementation process was broken. Even if the schedules produced were robust and logical they would be of little practical use because of lack of understanding.

4.1.5 Findings

The literature disclosed several gaps in literature. Firstly, there is some evidence of the use of lean construction in the Australian EC industry. Whilst, Nguyen (2013) report on workshops delivered to clients in engineering construction, briefing them on lean construction tools, little detail is offered on the implementation itself. The SC also pioneered the use of lean construction on completion and commissioning scope of work by the SC on the neighbouring LNG project (Morgan and Coci 2012). Yet, for the most past implementation of lean construction appears relatively immature in the Australia EC industry. Therefore, quantitative analysis was undertaken to ascertain the appropriateness of the approach for the sector. This revealed potential waste, including transportation and movement on KGP refurbishment projects. The most important element of lean construction is waste reduction (Green 1999, Ballard and Howell 2003, Jorgensen and Emmitt 2008, Mao and Zhang 2008, Eriksson 2010), with efficient storage and transportation of parts and materials, crucial to reduction of waste (Eriksson 2010, (Fearne and Fowler 2006). Therefore, lean construction was demonstrated as an appropriate antidote to the waste revealed.

A further gap was addressed in this chapter, where there is little evidence of research into the EC workforce culture and environment. The research investigated the workplace environment, the culture and abilities of the workforce. This research informed the application of the AR where insights from the observational research were used to inform the lean implementation. It should be noted that the researcher had no express mandate from the SC to implement lean construction tools, swimming against the rip tide of ongoing mandated PI consultant led productivity initiatives. However, the workforce, supervision and management for the most part far exceeded any expectations one could reasonably have, helping and engaging, often expending valuable time and effort.

The workforce deals competently with H&S issues peculiar to this high-risk environment. Furthermore, the environment shapes the workforce culture. A high value is placed on the ability to endure the tough conditions and especially for supervisors and managers to have instant recall of data and information and to present this in an accepted manner. The H&S prestarts revealed informal leaders facilitating knowledge transfer and being instrumental in developing an awareness of the consequence of a blasé approach to H&S. They are prepared to challenge the status quo and authority, Nevertheless, they are also egalitarian, where everyone including the researcher would have to expect awkward and probing questions in front of an audience at some point in time. The informal leaders identified were most likely to be the early adopters of the lean tools and then lead implementation. The research also demonstrated audience interaction and engagement in the H&S prestarts. The pre-start meetings were effective when controlled by the workforce and thought provoking when people related personal experiences. They were less effective when management intervened with directive speeches. There is no apparent research describing the potential of these meetings in informal leaders' identification and development, or as a place where people could challenge authority and share experiences and stories.

The culture can predominantly be described as a clan culture. This is described as a culture which values loyalty and collaborative teamwork, (Oney-Yazici et al., 2006, Arditi et al., 2017). Success is measured in terms of fulfilling customers' requirements (Cameron and Quinn 2011). The workforce demonstrated the value placed on collaborative working by their engagement with the implementation of the lean construction tools, even with the extra time required in already busy days. Team loyalty was demonstrated by story-telling to keep each other safe at pre-start H&S meetings, the willingness to challenge management, the informal leadership provided and support given to the researcher. They demonstrated keenness to fulfil customer requirements by their engagement with the Health & Safety (H&S) mandates in the form of the H&S pre-starts and ISSOW implementation. They went further by autonomously developing tools providing enhanced value to the customer, with the customer defined not only as the end user, but whoever a work activity was handed off to.

The research and analysis demonstrated the extent of the issues encountered with CPM usage at the KGP. An initial quantitative analysis of secondary data produced by CPM reporting revealed a disconnect between reporting and the reality of work progression. This was followed by an analysis using NVivo software of the data from 21 semi-structured interviews. One finding was the lack of understanding many supervisory and even management staff had of CPM reporting outputs. Thematic analysis identified a lack of understanding of work flow by planners, caused in part by inexperienced personnel whose career paths did not engender the development of appropriate knowledge. Therefore, many planners lacked the "art of planning" (COM 1), with plans and schedules lacked logic (COM 3, 7). A reason observed for the lack of logic, was delinking of activities, used to "stop" plans going supercritical (COM 15), that is, where the actual end date is overrunning that set for the project. This was acknowledged as common practice (COM 12, 13, 14). Somewhat surprisingly, many of the supervisory staff struggled to read and understand relatively simple schedules. Rather than aiding the construction process, schedules caused stress and confusion (COM 16). This was caused by a lack of experience and training (COM 17, 18, 19). The proposed solution was the provision of suitable training (COM 18) and the use of collaborative tools such as the LPS (COM 16). The primavera software produced an added burden on the supervisory staff, which was the need to constantly collect data, to feed its insatiable appetite for input. The data was collected by supervisory staff, without the necessary training to carry out this task (COM 11) with collection of the data itself viewed as potential waste, putting an added time burden on supervisory staff (COM 8, 9). The CPM/EVM tool, as operationalised by primavera® software is a management by results (MBR) approach which relies on the quality of the input data to produce meaningful outputs. However, a misalignment was apparent between reporting and "reality" on the workface (figure 4:12, 4:13). The following chapter describes the implementation of the Action Research (AR) over 18-months.

5 The Action Research (AR)

5.1 Cycle 1 Shutdown Targeted Inspection Points (STIPS) Jan- March 2014

Figure 5:1 -LNG pipework inspections

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Figure 5:2-Scaffold for STIPS inspection

First implementation of the LPS with the integrated TWD was carried out on the shutdown targeted inspection points (STIPS) campaign, where the pipe work (figure 5:1) and vessels (figure 5:2) was exposed and inspected to record the extent and severity of corrosion. In total 240 inspections were undertaken between January and March 2014. Each STIPS represented a mini-project with scaffolded access erected, cladding and insulation removed, the inspection undertaken and the insulation and cladding replaced. Each STIPS group typically consisted of 12 people, including scaffolders, metalworkers, insulators and inspectors. This research involved working with two teams. These teams were completing the final three weeks of the STIPS campaign (figures 5:1, 5:2) with the EPCM contractor EPCM #1 and the Implementation Contractors (IC) IC #2 and IC# 3. IC #2 had reached the end of their contract scope. However, IC #2 and other IC workforce frequently moved between the IC organisations.

5.1.1 Constructing

Lean construction was used in the action research cycles with the use and development described below.

The Last Planner System (LPS)

The LPS is a production planning approach, consisting of several components with an aim to meet customers' requirements (Diekmann et al., 2004). The customer can be end user, but crucially is also anyone to whom a piece of work is handed. The SC and EPCM planners developed the master programmes scheduling the refurbishment works. Milestones, from these Critical Path Method (CPM) schedules informed the Weekly Work Plan (WWP). Here, the last planners (LPs) who were the IC and EPCM supervisors and superintendents, collaboratively planned assignments before they went live. This normally took ½ to 1 hour. The production management phase in each WWP meeting recorded completions and reasons for non- completion with real time data extracted in the form of percentage plan complete (PPC) metrics. Pull planning utilised decision makers including, project engineers (PEs), superintendents and supervisors. In contrast to CPM, planning starts from the final activity, working back to the first activity to develop a schedule. Here, it was eventually used to develop templates for master CPM schedules.

Team Work Design (TWD) development

A tool called Team Work Design (TWD) was developed during the primary research and integrated into the LPS. This tool was developed for several reasons. Firstly, it addressed the gap in literature regarding operationalising the concept of common understanding in teams (Pasquire and Court 2012, Pasquire and Court 2013). Secondly, it was implemented to aid the development of higher performing teams from existing ones. The term used to describe the tool changed as the research progressed. Initially it was referred to as Workshop First Run Informed Work Design (WFRiWD), as the tool used workshops developing First Run Studies (FRS) to develop continuously improved standard work design using Plan, Do Check, Act (PDCA) cycles. However, feedback from several sources suggested that the name was unwieldly and difficult to remember. Therefore, the name changed to Team Work Design (TWD), simply because it assists teams to collaboratively develop continuously improved work design. A PDCA approach was used, utilising workforce and management expertise and knowledge to develop continuously improved standard work.

5.1.2 Planning

The early stage of the cycle was used to identify the key stakeholders and informal leaders and then explain what was involved in the implementation of the lean tools. This early work included, seeking to gain engagement and commitment from management and supervisory staff. The shift prestart meetings occurred at 6:00am where EPCM management, supervision, H&S advisors and Quality Assurance/Quality Control (QA/QC) met for ½ hour to discuss all aspects of the upcoming shift work and report on the previous shift. The H&S prestart meetings, started at 6:30am, normally lasting ½ an hour.

The early period was used to identify informal leaders and those with pre-existing knowledge of lean or lean type approaches, who would assist in the implementation and embedment of the lean tools. Informal leaders are described as those who exert influence over other members of a group (Pescosolido 2001) and can influence team-mates through means other than formal authority (Hills 2014). An early outcome was the demonstration of the engagement of those members of the management and supervisory staff who had prior knowledge of lean or lean type approaches such as the member of the SC management team below.

Monday 6:00am- 6:30 am

Meeting with SC 21 and SC 15

Presented handouts on the weekly work plan (WWP) system, in the form of a handout on the six-week look-ahead.

SC 15 had previous experience in the use of lean construction and suggested that I put a piece together with some text that would describe exactly what is involved in the implementation. This could be then sent out to the stakeholders to inform them of what's involved and expected. (MEET 3: SC support, previous lean type experience).

However, despite following this advice it was proving difficult to get much interest or engagement from the EPCM teams, reflected on below.

Reflection on the implementation of the WWP

Once informal leaders were identified, the lean tools and their uses and potential outcomes was explained to gain understanding and commitment. Yet, this required a lot of time, which I found frustrating. Whilst people were generally showing some enthusiasm for the concepts, the enthusiasm was not being followed up with any action. It was proving difficult even organising meetings with the EPCM teams. In principle, people could see the possibilities and the potential but in practice were not prepared to commit time to organising the meetings to plan the implementation of the tools.

This was unknown territory. Previously, I had used these tools whilst working as a construction project manager, a position where it was relatively easy to implement and use the tools. Here, I had to learn to use a different approach. This included cajoling and the use of subtler pressure to move the process along. In addition, whilst I was getting assistance from the SC staff there was always the impression that they felt that this was just another in a long line of initiatives, they would help but their hearts may have been quite in it.

This was something I had to think carefully about and finally, after exhausting other avenues with only vague promises of help I had a conversation with the SC construction superintendent (SC 15) who had witnessed a lean implementation with a previous organisation. He had conversations with relevant EPCM stakeholders. As I result, I could set up the first meaningful meeting with the aim of describing the lean tools and the requirements for implementation *(MEMO 1: embedment set back)*

There were some early challenges in engaging the EPCM contractor as described. There were several reasons for this. There has been a considerable number of initiatives over time at the plant, initiatives that could then fall into disuse. This was referred to as “initiative over load” by some of the supervisory and management staff. Therefore, there was little initial interest in another initiative, not even mandated by the SC. In addition, the start of the research coincided with the time where the EPCM contractors and the implementation contractors (IC) had just arrived on site in their roles. They have more pressing matters to contend with than placating one researcher implementing another initiative, doomed to eventually fade and disappear. To overcome this inertia, discussions and meetings were organised with the EPCM team, including the following:

Monday 2:30pm

Meeting: EPCM 01 site manager

I went over to meet EPCM 01, as he hadn't replied to the e-mail asking to set up a meeting to discuss getting things underway with the lean implementation. He seems a bit snowed under with work and hesitant to get involved in another process. He e-mailed the relevant members of his team to set up a meeting for Friday afternoon, but did not seem very confident. I emphasised the point that we needed to get the initiatives under way next week at the latest. (MEET 4: embedment setback).

Following this early meeting with the EPCM contractor's site manager, I had to re-engage with the SC superintendent as follows:

Meeting: Discussion with SC 15

Discussed feedback from EPCM 01 and said that a meeting had been set up for Friday afternoon to discuss the implementation. SC 15 remarked that this would be too late and said he'd talk to EPCM 01 to see if he could improve on this date. (MEET 5: engagement)

The following meeting was then organised

Meeting to discuss implementation of LI tools with EPCM #1

Attendance included: EPCM 02 (EPCM 01 back to back), EPCM 01, EPCM 09, EPCM 13, EPCM 11, and SC 11

Handed out the hand-outs that I had compiled earlier, went through this, and explained the tools and how I expected them to work.

Good general interest. EPCM 01 is beginning to see some merit in the concepts, but still a bit cautious as would be expected.

The first WWP meeting will be with EPCM 11 on Monday at 1:00pm. We probably won't be looking at area 1C but he will populate the WWP for with some suitable activities, (MEET 6: engagement).

This chain of events was significant for a several reasons. Firstly, the intervention of SC 15 who had previous lean experience was a key factor in gaining engagement from the EPCM contractors. In addition, the back-to-back change over between the two EPCM managers EPCM 01 and 02 produced a more positive dynamic. Following on from this meeting and input from SC 01 the implementation of the lean implementation could finally begin.

5.1.3 Taking Action

This phase of cycle 1 involved engaging with EPCM and IC site management and supervision, to implement Daily Huddles (DH), develop Weekly Work Plan (WWP) meetings and Team Work Design (TWD) workshops. The aim of these were the development of supervisor centric production planning, more long-term planning with the pull scheduling and work structuring using the TWD. The first part of the LPS implemented was the DH, described in the following section.

5.1.3.1 The Daily Huddle (DH)

Figure 5:3-The DH in a quiet zone

The DH (figure 5:3) is a tool used in lean construction implementation. which the researcher had used previously on other projects. The DH was initially introduced on the Shutdown Targeted Inspection Points (STIPS) campaign. The work was undertaken by a IC #3 integrated team, which consisted of scaffolders, insulators, cladders and an inspector. The DH was introduced in a week where there was a requirement to complete all the targeted inspections by the 31st of March, the end of this week. It provided a forum where supervisory staff can exchange information on what happened on the previous shift and what the expected work as determined by the WWP to occur on the upcoming shift. The work being undertaken had been accelerated for completion, to a one-week period, from the original scheduled three weeks. The following are participant observation reports following the first DH:

Friday: 8:15 am, Temp 28º C

*Meeting**:** Daily Huddle*

All the supervisors down by 08:15. Good progress. Last four inspections will be completed today. Reinstatement completed today. The pressure will be off then. Will start dropping scaffolding later in day and will be complete on Sunday. (DH 1: engagement, synchronisation.

Reflection on DH

The early implementation of the DH was problematic. This was a tool that I had used infrequently, so needed a deeper understanding of the DH as a process. My initial intentions were to embed it as a part of the early morning prestart Health and Safety meeting. The main reason for considering this option was because the various supervisors were already using the existing prestart to identify and describe their work fronts for the upcoming day. After some thought and consideration, I rejected this for several reasons. This included the point that it would have taken a great deal of negotiation with the health and safety advisors and management to get this embedded. It eventually seemed to make more sense to have the DH at the workface itself, so supervisors involved would be able to visually identify the work being discussed. *(MEMO 2: evolution of practice)*

As discussed (MEMO 2) it took considerable time and effort to finalise the implementation method. The DH provides a forum for information transfer. Yet, there was an unintended consequence, where it set a time that supervisors and crews arrived at the workface. Where some of the workforce were arriving up to 45 minutes late, eventually everyone started arriving at the designated start time. Even at this stage evolution of practice was evident. Originally, the DH has held close to the work front which was noisy, making communication difficult. EPCM 05 proposed it be moved to a quite zone to make conversation more audible, a practice used thereafter (figure 5:3).

5.1.3.2 Weekly Work Plan (WWP)

The WWP meetings were implemented alongside the DH. The first production-planning meeting had outcomes as described below.

Time: 1:00- 1:30 pm *Monday*

Meeting: First WWP Meeting

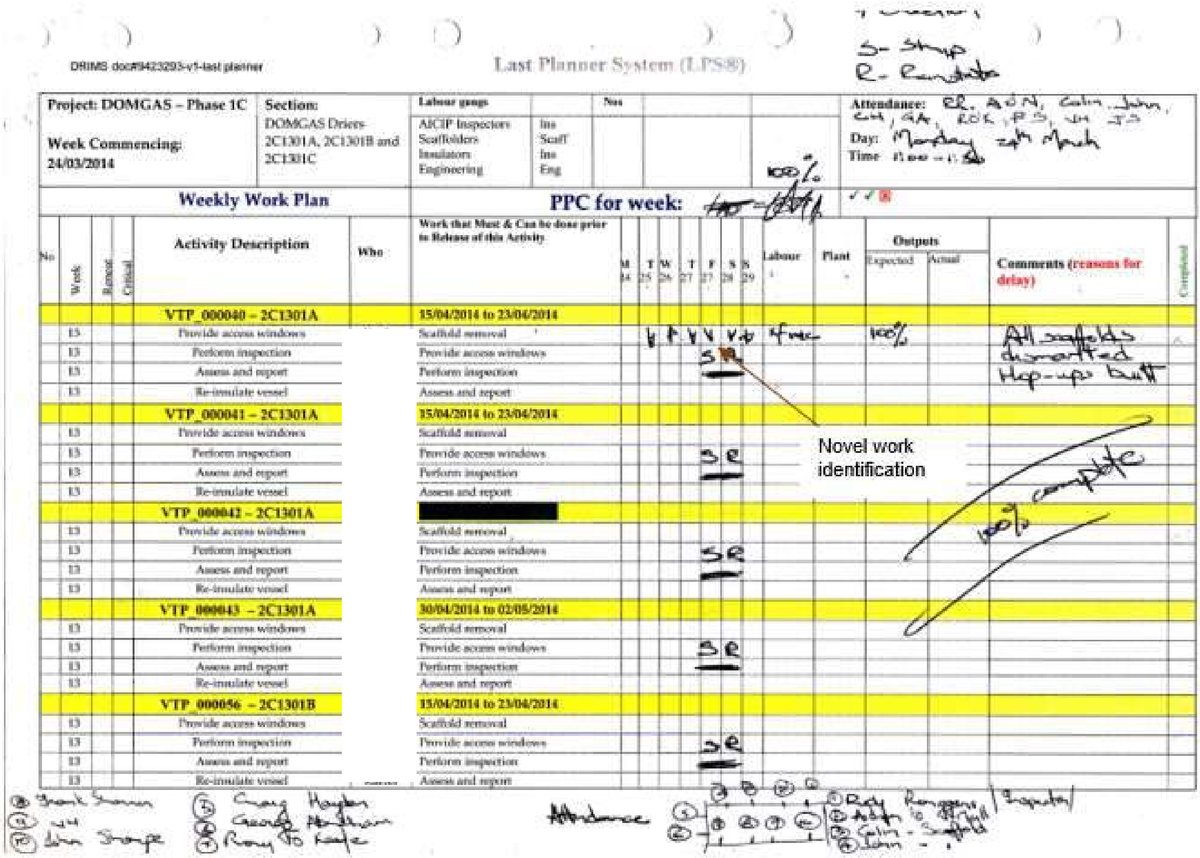
Attended by, EPCM 11 (EPCM#1 site engineer), EPCM 02 (EPCM#1 site manager), John (EPCM#1 supervisor), IC 03, IC 04, IC05, IC06, EPCM 14

Relative good start with some good interaction between the trades. Programme of works agreed for the upcoming week, (WWP 1: engagement, synchronisation).

There are two parts to the WWP meeting. In the first meeting the LPs, the supervisors staff involved in the planning, commit to activities in the upcoming week, identifying constraints, and how they can be removed. In the subsequent and all other meetings, the first item on the agenda is the feedback session. In this, the LPs report on the successful completion of tasks committed to in the previous week. In that way data is collated in the form of the plan percentage, complete (PPC), a metric derived as follows.

$$PPC = \frac{\#\ activities\ fully\ completed}{\#\ activities\ planned} \times 100$$

The production planning process is carried out as follows (figure 5:4). The LPs; decision makers leading the work scope implementation meet to collaboratively agree the upcoming production planning. Firstly the “Activity Description” details workscope, in this case informed by what the CPM schedule says what SHOULD be done. The appropriate LP (“Who”), commits to a work activity. A discussion ensues on identification and removal of constraints (“Work that Must and Can be done prior to the Release of this Activity”). A commitment can only be made on the timings once a work activity is deemed constraint free. The LP then commits on production timings, plant and labour requirements and predicted outputs.



DRIMS doc#9423293-v1-last planner

Last Planner System (LPS®)

Project: DOMGAS – Phase 1C

Week Commencing: 24/03/2014

Section: DOMGAS Driers 2C1301A, 2C1301B and 2C1301C

Labour gangs: AICIP Inspectors – Ins; Scaffolders – Scaff; Insulators – Ins; Engineering – Eng

Attendance:

Day:

Time

Weekly Work Plan

PPC for week:

No	Week	Ready	Critical	Activity Description	Who	Work that Must & Can be done prior to Release of this Activity	M 24	T 25	W 26	T 27	F 27	S 28	S 29	Labour	Plant	Outputs Expected	Outputs Actual	Comments (reasons for delay)	Completed
				VTP_000040 – 2C1301A		15/04/2014 to 23/04/2014													
	13			Provide access windows		Scaffold removal													
	13			Perform inspection		Provide access windows													
	13			Assess and report		Perform inspection													
	13			Re-insulate vessel		Assess and report													
				VTP_000041 – 2C1301A		15/04/2014 to 23/04/2014													
	13			Provide access windows		Scaffold removal													
	13			Perform inspection		Provide access windows													
	13			Assess and report		Perform inspection													
	13			Re-insulate vessel		Assess and report													
				VTP_000042 – 2C1301A		[redacted]													
	13			Provide access windows		Scaffold removal													
	13			Perform inspection		Provide access windows													
	13			Assess and report		Perform inspection													
	13			Re-insulate vessel		Assess and report													
				VTP_000043 – 2C1301A		30/04/2014 to 02/05/2014													
	13			Provide access windows		Scaffold removal													
	13			Perform inspection		Provide access windows													
	13			Assess and report		Perform inspection													
	13			Re-insulate vessel		Assess and report													
				VTP_000056 – 2C1301B		15/04/2014 to 23/04/2014													
	13			Provide access windows		Scaffold removal													
	13			Perform inspection		Provide access windows													
	13			Assess and report		Perform inspection													
	13			Re-insulate vessel		Assess and report													

Figure 5:4- first WWP sheet produced (*DOC 1: Evolution of practice, observable tool impact, team autonomy*)

The attendance and support of the EPCM site manager was significant, as it conveyed to the participants the value he saw in the initiative. However, the LPs started to evolve practice even at this early stage of the process. Normally the LPs each have a sheet, which they populate individually as part of a collaborative process, making commitments, discussing the removal of constraints and predictions of work to be completed in the upcoming week. However, in this instance the LPs handed the WWP sheet around the table with each LP filled in the sheet (figure 5:4) using their own code to identify the erection and dismantling of the scaffolding in each location. Although not obvious at first glance to someone else reading the WWP, the coding made sense to the LPs. In a subsequent conversation about the event, Glenn Ballard (the originator and leading expert on the LPS) remarked that this was a perfectly acceptable development as prime purpose of the WWP was to aid the LPs in their weekly look ahead planning process. The LPs are the people who need to understand the completed sheet and can use whatever approach suits when developing the weekly production planning.

5.1.3.3 Team Work Design (TWD)

As part of the feedback session the LPs also reviewed the work they had carried out, looking at lessons learned and proposing some improved ways of working from insights gained (figure 5:5).

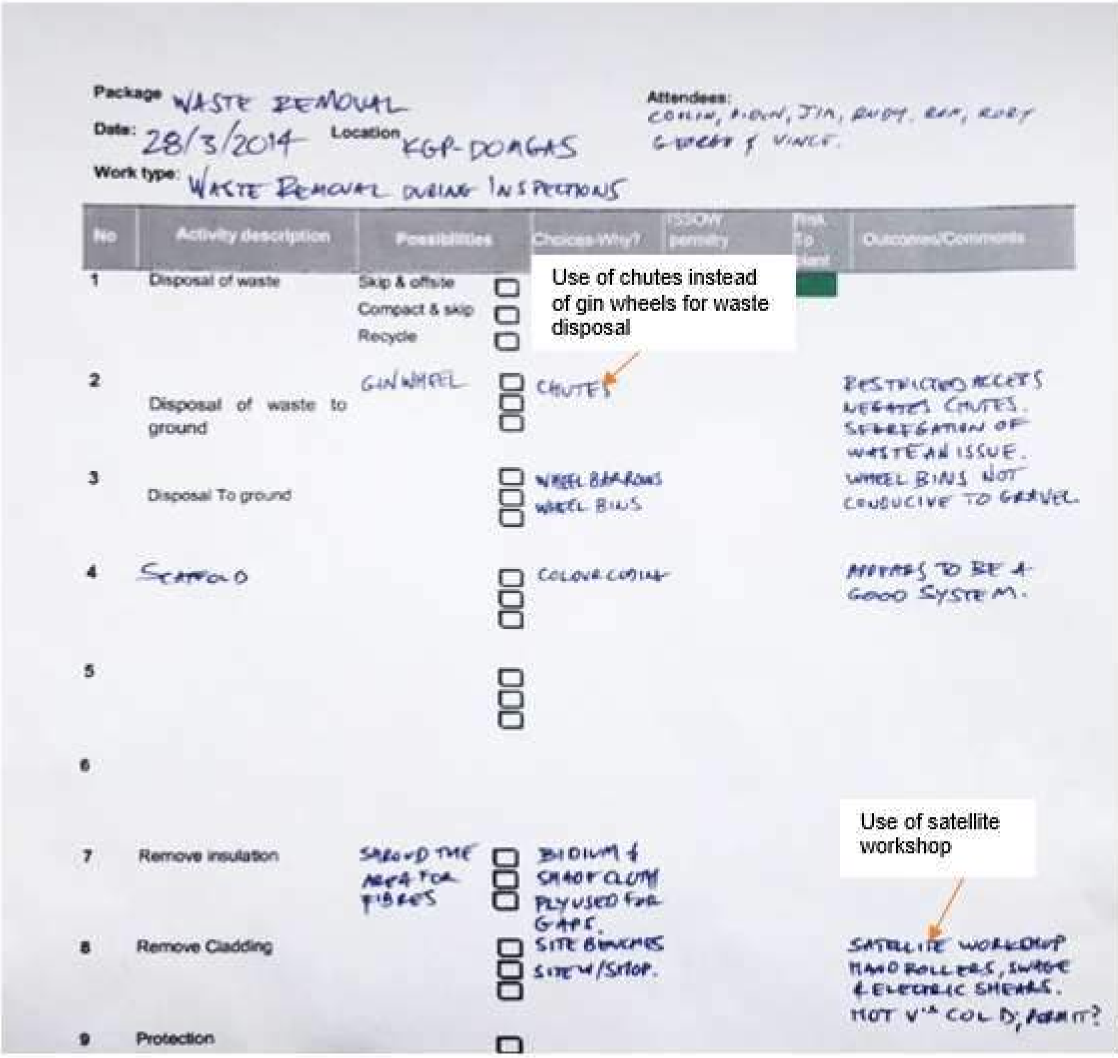


Figure 5:5- First WWP feedback **(**DOC 2: observable tool impact)

A further workshop to develop standard work was implemented immediately after the completion of the STIPS scope. There had been quite a degree of good will built up during the completion of this work. This was aided by the successful outcomes of the WWP. Therefore, the supervisors were engaged and willing to put some time aside to undertake the workshop. The attendees included the EPCM project engineers (PEs) who had led the implementation of the work scope and the LPs involved in the WWP during the completion of the work scope.

Earlier developed pro-forma was used as a boundary object in the discussion and development of standard work improvements. This was the Plan phase of the PDCA cycle (figure 5:6) below

Friday: 1:00pm

Meeting: First TWD

Attendees: VH, EPCM 02, IC 07 (planner), EPCM 11 (EPCM#1), IC 03, EPCM 14, SC 11

The conversation moved on to the possibility of learning lessons and developing standard work for the Domgas shut down which is scheduled for the end of April.

Look at permitary:

This could be rationalised and made a bit more user friendly. This question has been asked in the past by the workforce (SC 11).

Possible use of chutes instead of the current gin wheels for conveyance of waste to ground. The fabrication shops form a bottleneck in the shut downs with too many people trying to use them. Satellites fab shops could be set up to suit. We could initially try for hot work permits for these. If that's not possible, we could go for cold work permitary. Use of off- site manufactured benches instead of the current on site-fabricated benches was also discussed (WS1, engagement).

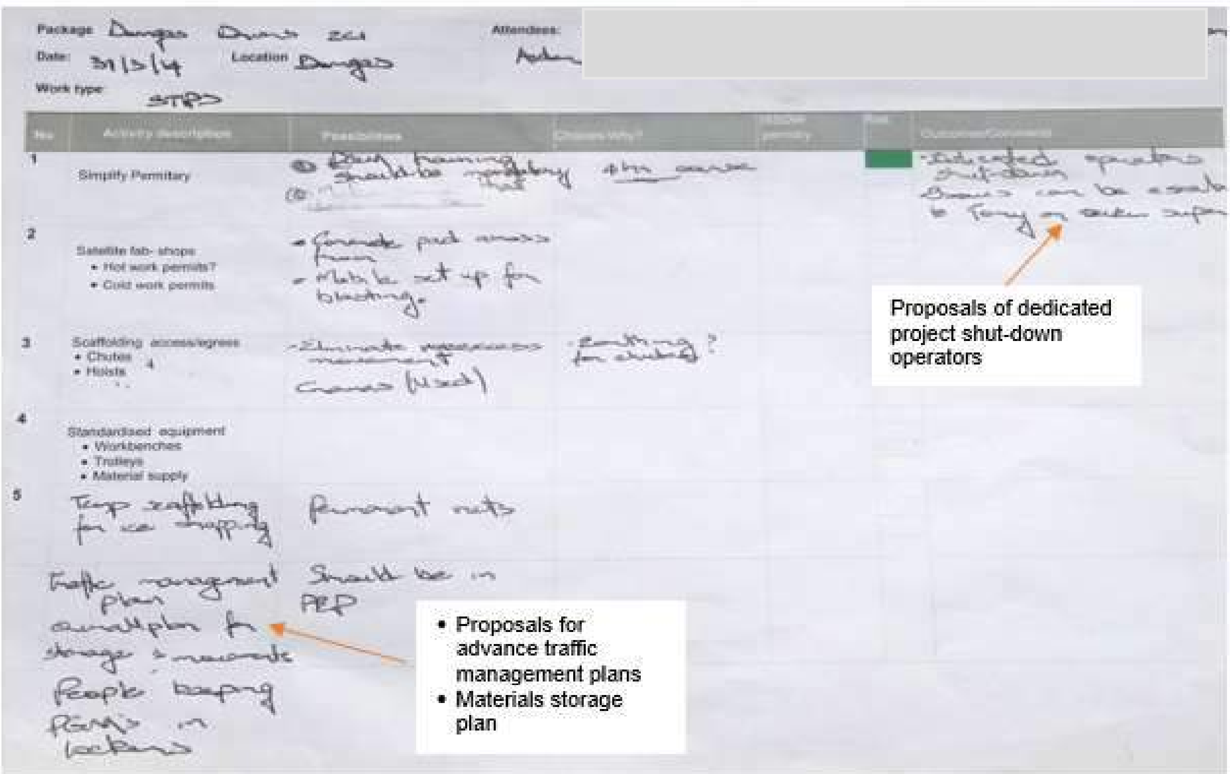


Figure 5:6- form used to in the TWD workshop *(DOC 11: evolution of practice)*

There were some positive outcomes from this workshop, with discussion on several ideas that could be used to develop improved standard work. The main outcome, however was the demonstration of LPs willingness to engage in the workshop, to develop practice that could be trialled on-site in the Do stage. In this case, this was an exercise to test engagement and the tool's potential. The limitation was that the outcomes could not be trialled as this work scope was now complete with crews broken up.

5.1.4 Event Descriptions and Outcomes

The following is a tabular report on the outcomes of the implementation of the DH and the WWP meeting. Key issues have extracted, placed in chronological order and colour coded below to identify the outcomes, varying from "poor outcome" to an "evolution in practice". In this, trends are identified, in the case below (table 5:1) poor outcomes were initially encountered in the DH followed by observed improvement in practice and finally "good practice" observed.

- (red) - Improvement required
- (blue) - Some visible improvements
- (yellow) - Improvement in practice
- (green) - Good practice
- (purple) - Evolution in practice

Cycle 1-Use of the DH on the STIPS campaign				
	Date	**Time**	**Event and Outcomes**	**Issues raised/resolved**
1	Tues 25 Mar	8:30am	Walk around on site with EPCM site engineer, Met EPCM superintendents (2 No)	One superintendent critical about the process of implementation and opposed to researcher interfacing with his crews
2	Wed 26 Mar	8:15am-8:50	Only inspector and one supervisor present on time. Other two supervisors 35 minutes late (collecting harnesses etc.)	Slow start due to permitary sign on Concern about potential confined space
3	Thur 27 Mar	8:15am-8:30	All supervisors and inspector on site in time apart from one who was 15 minutes late	After discussion, LP's decided that with some reorganisation critical work could be completed 2 days early
4	Fri 28th Mar	8:15am	All supervisors on time. Good huddle. EPCM 05 proposed the moving of the DH into a quite zone away from the plant noise	Inspections finished 3 days early. The DH now being used as a forum to transfer information

Table 5:1-DH first use

Cycle 1 –Implementation of the WWP on the STIPS campaign				
	Date	**Time**	**Event and Outcomes**	**Issues raised/resolved**
1	24 Mar	1:00pm	First production planning meeting.	The LPs already evolving practice.
2	28th Mar 2014	1:00pm	Feedback on the previous WWP Achieved a 100% PPC due to completing all the accelerated work.	The supervisors had improved on the work sequence once they realised that the aim was to enable the inspectors to complete inspections as quickly and efficiently as possible.
3	Mon 31st Mar	1:00pm	The reporting phase used as a forum to capture learning and good practice at a site level. There was good engagement in this process.	Use of the WWP process as a learning tool.

Table 5:2-Weekly Work Plan meeting outcomes

	Cycle 1- Implementation of TWD on Domgas 2 (DG2)			
	Date	**Time**	**Event and Outcome**	**Issues raised/resolved**
1	28 Mar 2014	1:00pm	Good engagement from the LPs in this process.	A need to implement the outcomes of the early work structure development workshops

Table 5:3-TWD outcomes

Summary

This initial implementation of the DH and the WWP demonstrated some successful outcomes. However, the implementation was not initially an easy process. After some early setbacks (MEMO 1), embedment was facilitated (MEET 3) by SC 15 who had previous experience with lean tools. This demonstrated the importance in seeking engagement from such people. This was followed by engagement demonstrated where the EPCM managers, after early scepticism (MEET 4, 5) eventually engaged (MEET 6), attending the DHs and the WWPs, Again, this engagement was critical to the success of the implementation. There was a demonstration of the need to adapt tools, in this case the DH to suit an environment (MEMO 2).

An analysis of findings in tables 5:1 and 5:2 reveal some of the following issues. The implementation of the DH gained momentum after poor outcomes from the first two attempts. There is some literature on the subject which speaks about the tool as an information transfer mechanism between supervisors (Salem et al., 2005, Aziz and Hafez 2013), but there was evidence of an outcome the researcher had not expected, which was workforce capability to evolve the tools (DOC 1). There were further outcomes observed, not identified in literature. Firstly, the DH ensured all supervision and crews were at the workface at the agreed time. In addition, the workforce was showing an early ability to evolve the forum usage to suit their purposes. As well as sharing information, which is the documented use of the tool, they also used the forum to make offers of help and make commitments on work to be completed on the upcoming day. This engagement coupled with synchronisation of the LPs, where they would work together, developing innovative practice.

The outcomes from the WWP meetings are summarised in table 5:2. This had a very short implementation period but gained early momentum. It had some clear positive outcomes including a follow up workshop using contemporaneous lessons learned to develop innovation practice. There were some reasons for this success. The primary one was the introduction of the tools into a group under severe pressure to complete many inspections in a short space of time. Because of this, they were willing to try anything that might help achieve that outcome. There was initial scepticism on the part of the EPCM managers. The engagement of these managers was critical as they are highly experienced and respected, having full control of all operational aspects of the EPCM work scope. Successful WWP outcomes was not achieved again until much later in the lean implementation process.

The first TWD workshop was undertaken in this cycle with limited success. The LPs engaged in the workshop, using their experience and knowledge to propose work practice improvements. However, as this work scope was completed for the time being, the proposals could not be progressed into the DO phase of the PDCA cycle. A further outcome was the demonstration of a positive correlation between high PPCs and time performance achieved, where in this case a PPC of 100% was reported for work scheduled for 3 weeks, subsequently planned for completion by the LPs in 7 days but completed in 5 days.

5.2 Cycle 2 Domgas 1: (May – June 2014)

Figure 5:7-night shift

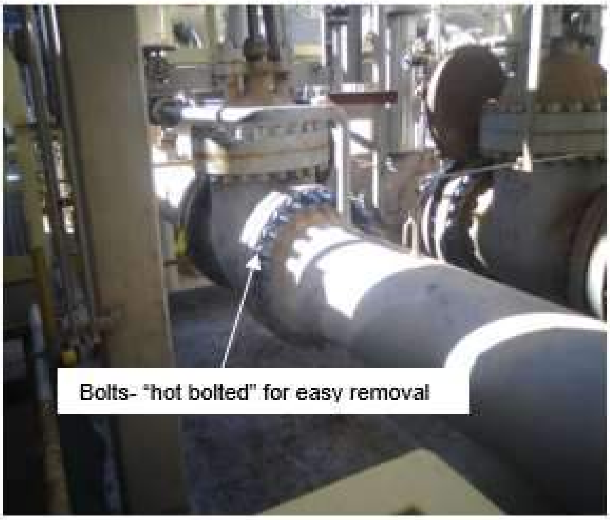


Figure 5:8- valves "hot-bolted" prior to removal

This work involved an outage of the Domgas 1 train, which supplies gas to the domestic market (figures 5:7, 5:8). Both trains 1 and 2 supply a significant volume of Western Australia's natural gas requirements. The work scope consisted of the replacement of valves and pipework with the associated insulation and cladding scope and the refurbishment of exchange vessels. The LPS was implemented on the shutdown scope with work undertake on a 24-hour basis over a 30-day period. The EPCM contractor EPCM #1 and the implementation contractor (IC) IC#1 with the work force consisted of approximately 60 people with 30 workers on the day shifts and 30 on nights. Qualitative data was gathered from sources including attendance at H&S pre-start meetings, EPCM shift prestart meetings, meetings including WWP meetings and informal conversations with stakeholders.

5.2.1 Constructing and Planning:

The constructing and planning phase of cycle 2 were combined and included a review of the implementation of the tools in cycle 1, discussions with participants on what they felt went well, and what could have gone better. Some of the comments included that WWP sheets produced in the previous cycle was easier to understand than those from external projects. People could identify more easily with the WWP sheets undertaken on work scope at Karratha. This point demonstrated the importance of context when seeking to implement the lean tools. People could engage more easily with examples they could relate to. The time agreed for the meeting was also critical to success where a time had to be agreed by common consent. After much negotiation, this was set for Fridays at 1:30pm. The importance of fully explaining the use and reasons for use of the DH and the WWP when new supervision is involved was also recognised.

The DH in cycle 1 had gone well with the participants acknowledging the benefits. Still, there was an eventual challenge from the SC site manager on the DH timing. This was something to reflect on, as described below.

A challenge on the implementation assumptions of the DH

There was a challenge from the SC site manager that the DH could start earlier at 7:40. Following input and support from the SC supervision and discussion with the EPCM contractor the start time was set at 07:45, with the expectation that work would start 30 minutes earlier than previously.

This was an interesting juncture in the research. The DH was now setting the time, work started on site. The costs of time lost while workers were not on the workface in the mornings were quite substantial. Yet, this was the first time that SC site management raised a question as to the timing of the DH *(MEMO 3: Evolution of Practice)*

The planning phase included discussions and meetings with the EPCM contractor EPCM#1 and the implementation contractor IC#1. The following are some minutes of the first meeting, used to establish a rapport with IC#1, to explain the tools and their usage, to identify the potential LPs and to promote an understanding of how the tools are used.

> *Monday 10:30- 11:00 am*
>
> *Meeting; with IC 11 (IC#1 Site Manager) and IC 02 (IC#1 site co-ordinator)*
>
> *Temp; 32º C and Sunshine,*
>
> *Positive meeting with IC#1. They are keen to implement the WWP. IC 02 (IC#1 implementation superintendent) and some of the other superintendents have started looking at the WWP. IC 11 was keen to implement the WWP where possible. He will get back on the scope options and the likely crews. I said that we need to have integrated teams. (MEET 6.1: engagement)*

Nevertheless, engagement proved more elusive than cycle 1, as illustrated by the following meeting

> *Spoke to IC 02 re starting up the WWP. He seems to be quite stressed and very busy sorting out issues with scaffolding supervisors, providing adequate reporting and feedback*

on completions and % completions and was not particularly focused on implementing the WWP (CON 4: resistance).

Despite several discussions during the week with IC 02, progress was slow. This demonstrated the amount of time and patience required to embed the WWP tool. After the conversation above and some consultation, the following meeting was convened.

Monday Time 11:00

Went through the populated WWP with IC 02. This went much better and IC 02 is developing some understanding of the lean concepts, (MEET 7: engagement).

The constructing and planning stage took a lot of work and time, to enable the implementation of the next stage, “taking action”. This is described in the following section.

5.2.2 Acting

5.2.2.1 Daily Huddle (DH)

Following lessons learned on cycle 1, the DH was carried out at the workface at a designated time (7:45 am) prior to work starting. This included the LPs but was also open to management. The first DH was poor, again with a degree of miscommunication demonstrated. The following is a report of the first DH carried out on the Domgas 1 shutdown scope of works.

Monday 8:00am, Temp 28º C

Meeting: DH at Domgas 1 work-front.

*Went down on site the for daily huddle. IC 05 was the only supervisor down at the humpy (temporary shelter, the name comes from an indigenous word). We got started at 8:15. Mikey had some miss-information from IC 02 and was under the impression that he had to record progress daily. This seemed to stress him quite a bit. We had a discussion and I explained what was needed was a quick 10-minute discussion on what went well and less so yesterday and what the progress was to be followed by a discussion about the upcoming day’s work. This went relatively well. IC 05 mentioned that there were simops (*simultaneous operations) *issues with EPCM #2 on scaffolding for the furmanite clamp. We had been aware at the WWP that this could be an issue, but realised that EPCM #2 should have attended the WWP meeting and in future we would need everyone working or potentially working in the work scope area.*

Had a conversation with SC 13 who had come along to observe and his comments were that we needed all the supervisors and relevant EPCM #1 and IC #1 management present at these daily huddles (DH 2: embedment setback).

There was a clear lack of engagement from the LPs and improvement was required. The earliest any of the supervisors arrived on site was 8:15am with other supervisors arriving at 9:20 am. Following conversations and consultation with SC supervisors the following e-mail was sent to contractors.

Gents.

Can you please inform all your contractors to get their supervisors to attend a 7.40am last plan discussion with Vince? We want this to be a mandatory attendance for all supervisors with active work fronts. Only Domgas at this stage. We have moved from 8.00am to put a stretch target on the Supervisors.

Any issues please let me or Vince know.

(E-mail 1: SC support)

The next DH still needed improvement but had a strong presence from SC and EPCM#1 site management. Again, this demonstration of senior site management commitment (note attendance) had a positive effect.

Time: 7:45am
Event: DH

Attended: SC 09 (Superintendent), SC 13, EPCM 02 (site manager), IC 12 (site manager), IC 09, IC10

This was still disorganised. Many of the supervisors didn't turn up until 8:15. There was a lot of initial milling around while supervisors signed onto permitary. The PA's (performing authorities) can do this. EPCM 02 got a good conversation going around the points that were under discussion; reporting on the previous day and planning for the upcoming day. (DH 3, embedment setback).

The following day was the first where the LPs started to engage and turn up at the designated time for the DH, reflected EPCM#1 and SC management engagement and support. This was also the point where all those involved in the shutdown were now working a 12-hour day. The following is a reflection on some of the early learning from the early implementation of the lean tools and the importance of getting visible support from the SC's and the EPCM management and supervisory staff.

Reflection

SC input has enabled improved outcomes this week. The DH again took about three attempts before it started to function properly. There are some gains being observed from the DH including an agreed start time in the morning (7:45 now agreed with EPCM#1) where supervisors and workers are expected to be at the workface. This is giving a SC validation to the DH. The DH also provides SC, EPCM#1, IC #1 and other contractor management and supervisors with an opportunity in the morning to get a status report and a look ahead for the day *(MEMO 4: evolution of practice)*

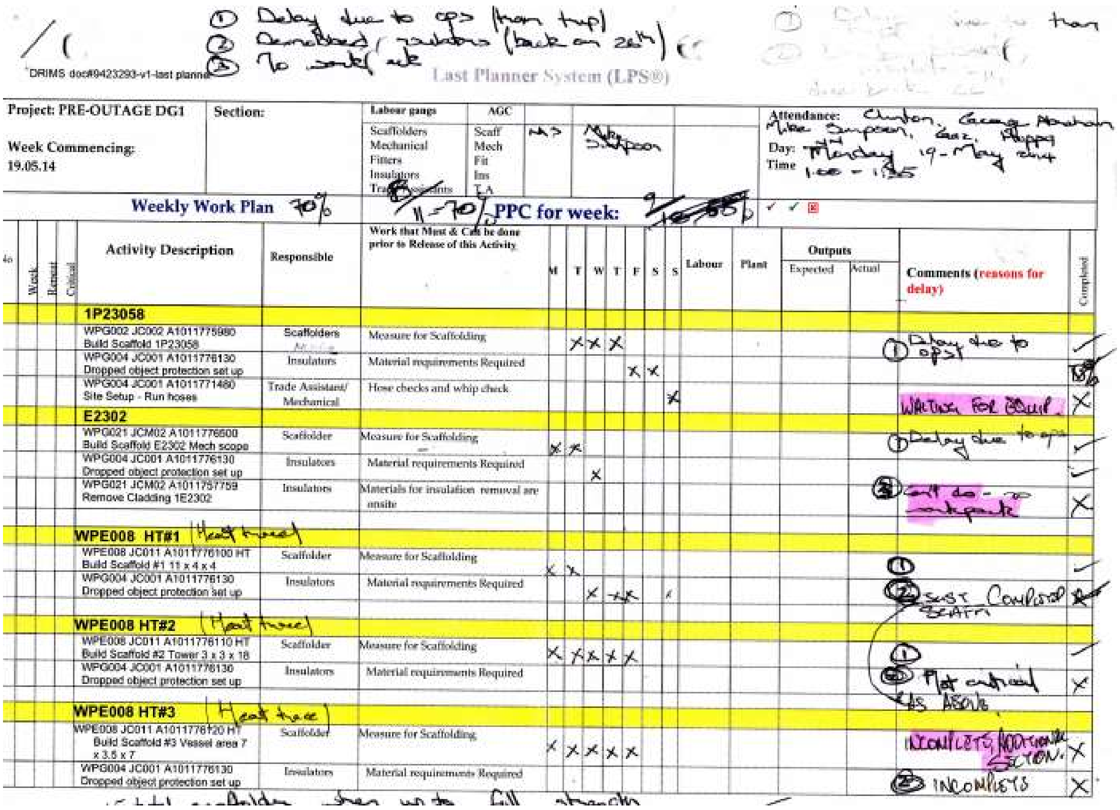
5.2.2.2 Weekly Work Plan (WWP)

The first WWP meeting with IC #1 had a poor outcome as described below. One of the reasons was a lack of clear CPM milestones to inform the WWP. In addition, a lack of understanding of the process and a lack of engagement was demonstrated. People were there for the most part under protest. However, again there was strong support demonstrated by SC and the EPCM management.

> *Saturday Temperature 32º C Time: 6:30-7:00am*
>
> *Meeting WWP meeting with IC #1*
>
> *Attendees: IC 02, EPCM 02, SC 15, IC 06*
>
> *This was a challenging meeting. The scope was limited to scaffolding and protection work for dropped objects with only one field supervisor present. Carried on with the introduction and used two examples of previous WWP implementation, the one at Maude Foster (UK) and the one carried out on the Domgas driers. The meeting has now been reset for Monday at 1:00pm (WWP 2; embedment setback).*
>
> The meeting had to be rescheduled as described for the following Monday. This meeting demonstrated better outcomes with more engagement. It was noticeable that the attendance of either EPCM site manager, explaining concepts and potential benefits, always had a positive effect on the meetings.
>
> *Monday, 1:00- 1:30 pm*
>
> *Meeting: WWP meeting*
>
> *Attendees: EPCM 02, IC 02, IC03, IC 10, IC 05*

This was a much better meeting attended by the EPCM site manager. I started this with a presentation of the main points. It took some time for the site supervisors to realise that they were not being held to pre-planned dates but were free to commit to dates and durations that they felt were achievable. (WWP 3; management influence).

This was one of the first WWP meetings in the cycle where the LPs started to engage. The site - manger EPCM1, again attended the meeting, explaining to the LPs why they should plan their work using the LPS approach. The following WWP sheet (figure 5:9), was produced to a high standard.



DRIMS doc#9423293-v1-last planner

Last Planner System (LPS®)

Project: PRE-OUTAGE DG1 — Section:

Week Commencing: 19.05.14

Labour gangs / AGC: Scaffolders – Scaff; Mechanical – Mech; Fitters – Fit; Insulators – Ins; Trade Assistants – TA

Attendance: — Day: Monday 19-May — Time:

Weekly Work Plan 70% — PPC for week:

Activity Description	Responsible	Work that Must & Can be done prior to Release of this Activity	Comments (reasons for delay)
1P23058			
WPG002 JC002 A1011775980 Build Scaffold 1P23058	Scaffolders	Measure for Scaffolding	① Delay due to ops
WPG004 JC001 A1011776130 Dropped object protection set up	Insulators	Material requirements Required	
WPG004 JC001 A1011771480 Site Setup - Run hoses	Trade Assistant/ Mechanical	Hose checks and whip check	
E2302			
WPG021 JCM02 A1011776500 Build Scaffold E2302 Mech scope	Scaffolder	Measure for Scaffolding	① Delay due to ops
WPG004 JC001 A1011776130 Dropped object protection set up	Insulators	Material requirements Required	
WPG021 JCM02 A1011757759 Remove Cladding 1E2302	Insulators	Materials for insulation removal are onsite	③
WPE008 HT#1 (Heat trace)			
WPE008 JC011 A1011776100 HT Build Scaffold #1 11 x 4 x 4	Scaffolder	Measure for Scaffolding	①
WPG004 JC001 A1011776130 Dropped object protection set up	Insulators	Material requirements Required	②
WPE008 HT#2 (Heat trace)			
WPE008 JC011 A1011776110 HT Build Scaffold #2 Tower 3 x 3 x 18	Scaffolder	Measure for Scaffolding	①
WPG004 JC001 A1011776130 Dropped object protection set up	Insulators	Material requirements Required	②
WPE008 HT#3 (Heat trace)			
WPE008 JC011 A1011776120 HT Build Scaffold #3 Vessel area 7 x 3.5 x 7	Scaffolder	Measure for Scaffolding	INCOMPLETE
WPG004 JC001 A1011776130 Dropped object protection set up	Insulators	Material requirements Required	② INCOMPLETE

Figure 5:9 -Completed WWP 19 May *(DOC 3: observable tool impact)*

The following are some reflections following this WWP meeting.

Reflection

It takes many attempts before a good level of engagement is achieved. It makes a big difference having the support of EPCM#1 management at these WWP meetings, particularly as following many conversations with them; they have a good understanding of the philosophy. Time must also be taken to make sure that the LPs fully understand their roles. On reflection, I have not been consistent in the use of language, expectations and how the implementation of the tools should be progressed. Because of this reflective process, I am proposing to develop a presentation and will run this by SC

11 (SC CI Karratha champion) on Wednesday before presenting to decision makers. *(MEMO 5; evolution of practice)*

It was only at this point that the LPs really engaged. There were some reasons for this. Firstly, the SC supervisory team applied pressure to the EPCM management. They indicated that the initiative had their support and it would be in the EPCM contractor's best interest to engage with implementation. After some initial resistance, the two EPCM managers proved ardent supporters, surpassing expectations in help given.

The following are the minutes from one of the first WWP meetings in cycle 2 where the LPs began to engage more and develop an understanding of the requirements.

> Monday 10:00 am, Temp: 30˚C
>
> *WWP meeting:*
>
> Attendees: *IC 01, IC 15 (Part time), IC 05, IC 10, IC 04*
>
> *IC 01 brought along all the supervisors. He is very keen on implementing the WWP and has been implementing it on his own when I was on rest and recreation (R&R). He is one of the top supervisors with a good knowledge of the use of the schedule. The WWP sheet wasn't pre-populated but IC 01 populated it from the schedule. The meeting went well. Reported a percentage plan complete (PPC) of 70% for last week. I mentioned that this would become a very important metric for them as time goes on. This was met with some scepticism. There was a discussion about considering work that hadn't been committed to but done. I said that only work that had been committed to could be included in working out the PPC but that 70% was a very respectable score. Good interaction and the meeting was worthwhile as some of the supervisors had just comeback from R & R (Rest and Recreation). (WWP 4: informal leader, engagement).*

However, there were still difficulties encountered in the implementation of the WWP as noted below. There were other issues at play, which were preventing engagement and understanding. This subsequently proved to be a lack of understanding on the part of many of the supervisors in the fundamentals of scheduling.

> *Friday, 1:00*
>
> *WWP meeting with IC 01:*

This again was not one of the better WWP meetings. There was no defined scope but IC 01 could confirm that the work would be split into 80% mechanical scope, 15% scaffolding mods, and 5% insulation cladding at the end. He didn't populate a WWP and said he would do this tomorrow. He hadn't done this because of his workload. It seems that when things get stressful is the time when people are least likely to engage with the WWP, (WWP 5; embedment setback).

Reflection on the Implementation of WWP in cycle 2

On reflection, despite some successes, it seemed that the implementation of the WWP was still patchy. The LPs were generally keen, but there was misunderstanding of the requirements and expected outcomes. I thought about how the process had being explained to date. Whilst meetings and discussions had been organised it seemed something was being lost in translation. Thus, I developed the following sheet called the Main Aspects of the LPS (figure 4:28), particularly as applied to the WWP meetings. This was to be used in further discussions and meetings, to provide a common message as to what was involved and relevant in the Last Planner System *(MEMO 6: evolution of practice).*

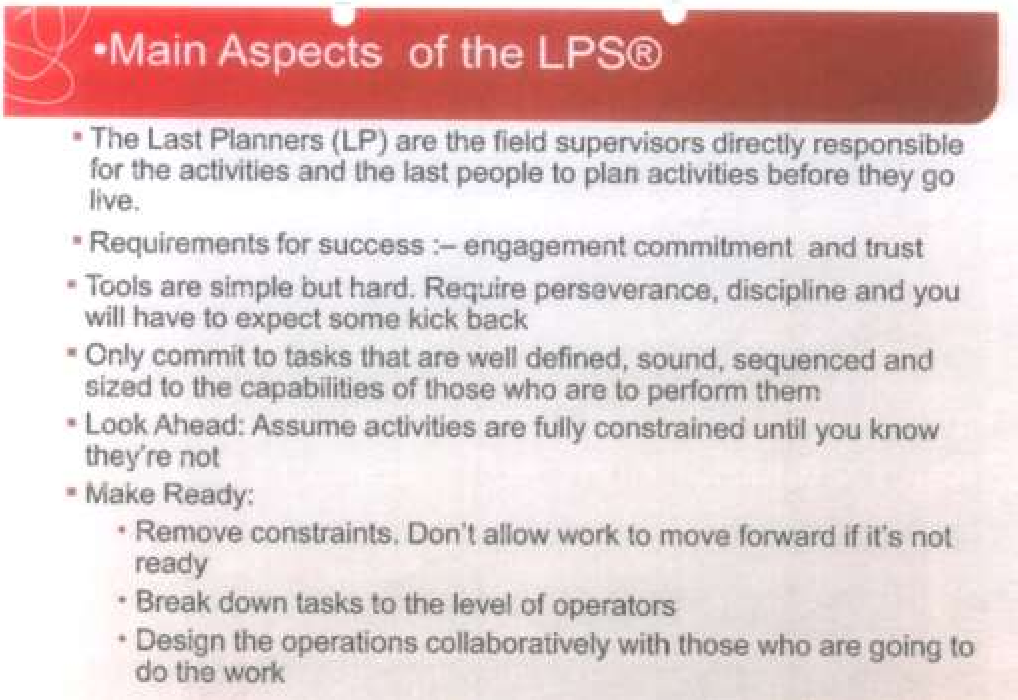


Figure 5:10- Main Aspects of the WWP *(DOC 4: evolution of practice)*

There was some improvement observed at the following WWP meeting, where problems were revealed when the constraints were examined. In this case, one constraint was the availability of spools. It transpired that there was uncertainty over whether the spools scheduled for installation were on site.

> *10:30 am Tuesday; Temp 29º C*
>
> *WWP meeting:*
>
> *Attendees: IC 02, IC 05, IC 06, IC 10, IC 09.*
>
> *The sheet had been pre-populated though it's still suspect if it accurately reflects the schedule. This had one desired outcome in that it highlighted that IC10 was committing to install dummy spools (14 ") but there was no certainty of where the spools were. IC02 started chasing this (The outcome of this was that they weren't on site and had to be delivered) (WWP 6; engagement, synchronisation).*

The following week's WWP meeting demonstrated continuing issues with the ability of the LPs to produce effective production planning. Still, this meeting demonstrated the continued EPCM management commitment to get the WWP embedded as a collaborative planning tool. The input by EPCM 01 was helpful, demonstrating a real understanding of the philosophy and an ability to explain it to the LPs. It also highlighted the fact that whilst there was IC superintendent and supervisor involvement at the meetings there was a need of corresponding input from the relevant EPCM supervisory staff. This was a missing link in the chain.

The WWP embedment progressed slowly with several factors including time availability and the understanding of scheduling and planning caused a drag on successful implementation.

5.2.2.3 Workforce Engagement

The cycle demonstrated workforce influence on the lean implementation. As described the pre-start meeting is a good forum for strong informal leaders to demonstrate their abilities. These were the people who went on to be the early adopters and who led the implementation of the lean construction tools. Some of these early adopters implemented the tools on their own initiative. However, not all informal leaders were early adopters or even keen on the lean approach at the early stages of the research with some offering resistance as follows:

Getting some push back from IC 09. He wasn't too keen on planning that he felt was going on behind his back and felt that the planning itself (WWP) wouldn't be of much use if the top-level Perth planning didn't align with the reality on the ground. He also felt that his authority would be undermined. (CON 2: resistance).

Not all resistance came from the supervisory staff with some subtle resistance emanating from management, where there was an early demonstration of the belief that time spent planning was unproductive time and that the workforce should be "working not planning".

Feedback from SC 01 and confirmed by further discussions with management that there was a sense of the WWP meetings wasting time and taking supervision away from the work fronts, it was more worthwhile that they should direct the work rather than be involved in "planning" (CON 3: resistance).

Kotter (1996) describes people who demonstrate resistance to change as naysayers. He regards these people as particularly disruptive when organisations initiate change. Luecke refers to these people as "resistors" and says that:

> *They perceive change as endangering their livelihoods, their perks, their social arrangements, or their status in the organisation… resistance may be passive or active in the form of direct opposition or subversion. How will you deal with that resistance? (2003, p.75).*

Luecke points to some strategies to deal with resistors, regarding these people as having a corrosive influence, where a few disgruntled individuals can subvert the whole group. Yet, this viewpoint did not align with the observed effects of the resistors at the KGP. It was clear that these people were exhibiting behaviour, where the workforce would challenge and question new initiatives. Yet, this early resistance usually turned to positive engagement when it was realised that the tools did not represent a threat to peoples existing authority. Others, whilst initially sceptical did eventually engage once they understood the concepts and could see the potential benefits. In many cases, early resistors became constructive critical advocates. Observation revealed that the first key to successfully embed the tools was the identification and engagement of informal leaders, with the second key the identification of people who had used lean approaches, or similar in the past and were comfortable with the principles and philosophy. There were several people with knowledge, (Gladwell 2000) including some of SC's superintendents, who had previous experience of lean type methods. They could grasp the concepts of the lean tools, were strong advocates and could pass that knowledge to others using narratives and conversations.

SC 15 has seen a system being used like lean construction before where an American company Nucore, involved in the recycled steel market, had implemented a lean approach. He noted that they are in the mini steel business and owned quite a few steel companies, which they must have bought up over the years. The company was quite large and very progressive to the point where bonuses are split quite equally between bosses and workers. SC 15 was working with these when they were doing a joint venture with Alcoa. The lean approach worked well but once the JV split up and Nucore left, the initiatives faded. (MEET 1: previous experience).

Other knowledgeable people included EPCM 01, one of the early adopters, who provided some of the strongest support. This support included coming in to work two hours early at 4:00am to sit in on the night shift WWP meetings, to motivate and lend support. EPCM 01 grasped the concepts at a very early stage and was one of the best people to articulate the philosophy and the likely benefits for the workforce once they engaged. He explains below his experience in using a similar approach:

The LPS is very similar to a system that I have used in the past if a bit more refined. You get in the room with the key people and literally use the room. It's something I probably knew but it gives the opportunity to set the gates up and move from one place to another. It's a bit more refined than what I've used in the past, just moving around the walls with post-it's when going through the CCLBD (construction and commissioning block diagram) logic. It gives ownership to everyone, down at the coalface, (MEET 2: previous experience).

The following section describes the outcomes of this cycle.

5.2.3 Events Descriptions and Outcomes

- (red) - Improvement required
- (blue) - Some visible improvements/ some engagement
- (yellow) - Improvement in Practice
- (green) - Good practice
- (purple) - Evolution in practice

Cycle 2- Use of the DH on pre-shut and shutdown on Domgas train 1				
	Date	Time	Event and Outcomes	Issues raised/resolved
1	19 May 2014	8:00-8:20	Only one supervisor. Not down until 08:20.	Misunderstanding about requirements. There was a misperception that the DH was a progress monitoring tool.
2	22 May	7:45am - 8:00	DH very disorganised. Many supervisors turned up at 8:00am. Confusion as they signed on to the permits.	Supervisors do not need to sign onto permits. PA's can do this and free up supervisors. Work started late.
3	22 May	12:45	Meeting with SC site manager. Challenge as to why the DH time could not be set earlier at 7:40am. Organised further meeting with SC 13.	First time issue raised that the DH should start at a designated time.
4	22 May	2:00pm	Discussion with SC 12 re start time of DH, agreed that this time could be 7:40am. Sent e-mail to EPCM #1 management requesting a 7:40 am start.	
5	22 May	4:00pm	Discussions with EPCM #1 management. DH start time set at 7:45 after discussion with EPCM management and superintendents.	.
6	23 May	7:45am	Good huddle, IC #1, SP and EPCM #2 site managers present and all relevant supervisors. Good interaction and start to work. Information given on lessons learned during the previous shift.	.
7	Sat 24 May	7:45 am	Good huddle (from feedback) – researcher not present.	Demonstrating good practice occurring without researcher facilitation.
8	Mon 26 May	7:45 am- 7:55	Everyone on time, IC #1 EPCM #1 management and supervision.	
9	Tues 27 May	7:42- 7:50am	Very good DH. The DH is now setting the time that supervision and workers get on work site.	Demonstration of the use of the DH to set the time work starts.
10	Wed 4 June	6:40am- 6:47	Good DH. This starts ½ hour earlier in a shutdown.	
11	Fri 6th June	6:45pm- 6:52	Good DH. This demonstrates cross-over to nights without the presence of researcher.	The DH is now one of the formal site meetings.
12	Mon 9th June	6:40am- 6:47	DH now being used by HSE advisor and QA/QC when they need to get a message out for the day.	The researcher has not witnessed this behaviour before.

Table 5:4-Implementation of the DH Cycle

Cycle 2- implementation of WWP on DG1				
	Date	Time	Event and Outcome	Issues raised/resolved
1	Mon 12th May	10:30 am	Meeting with IC #01 to discuss the implementation of the WWP and agree some timings.	Timings agreed.
2	Tues 13th May	3:00pm	Conversation with IC #01 field coordinator.	Difficulty in obtaining buy in and engagement.
3	Sat 17th May	6:30- 7:30am	First WWP. Poor outcome, lack of engagement and understanding.	
4	Mon 19th May	10:30am -11:00	Repeat WWP. Improved outcome.	There's still a lot of work to do on implementation process.
5	26th May	10:00 am	WWP with back to back coordinator IC 01 and supervisors. The LPs were keen and engaged.	
6	Fri 30th May	1:00- 1:30pm	WWP with IC 01 and supervisors. Poor WWP, lack of understanding and engagement.	The WWP outcomes are variable, quickly turning from good to poor.

Table 5:5- Cycle 2 Implementation of the WWP

Summary

An analysis of the coding and outcomes tabulated in table 5:4 and 5:5 above demonstrate the difficulty encountered in reintroducing the tools in a new cycle. There was early resistance (CON 4) and poor implementation outcomes encountered (table 5:4 Items 1,2). SC support (e-mail 1) proved critical in ensuring momentum in the re-embedment of the tools. This included a challenge on the timing of the DH (MEMO 3), resulting in an earlier start to the working day. This confirmed the importance of obtaining client buy in and support. Practice (table 5:4 item 6), not apparent from literature was exhibited, where site management, including the SC came to the DH. After some early difficulties, the DH was re-embedded where everyone, even SC management or supervision (if present) deferred to the huddle leader. There was an evolution of practice, with an implicit consent that an EPCM manager if present, or otherwise one of the EPCM superintendents would lead the huddle. It was viewed as a forum aiding the transfer of real time information and data between the participants prior to work starting on each shift. Table 5:4 item 11 revealed the supervisors setting up their own DH on the night shift, demonstrating their ability to engage with the lean tools with a minimum of facilitation. Table 5:4, Item 12 exhibits another change that the researcher had not witnessed before. The H&S and the quality control (QA/QC) advisors now viewed the DH as something they should attend, perceiving it as a valuable forum to convey key data or information to the workforce. Yet, even at this early stage, the DH was an indicator of early shift workflow and synchronisation. If the DH started late with a lack of workforce synchronisation (table 5:4, item 2 and DH 2, DH 3), subsequent workflow was poor and disorganised. Conversely a timely synchronised start (table 5:4: items 6, 7, 8) augured a good start to the day’s work.

A reflection on implementation progress (MEMO 6) rationalised that one of the reasons for the patchy workforce re-engagement was a lack of a clear message. This prompted some evolution in practice with the development of a sheet (DOC 4). This sheet describes the main WWP expectations. This was used in subsequent WWP meetings. Table 5:5 demonstrates issues encountered in the WWP implementation. The WWP should be held at a set time each preferably on Fridays, so next week’s planning can take place close in time to the week start. However, there was difficulty experienced in obtaining this disciplined approach (table 5:5 items 3-6). Furthermore, the poor outcomes experienced (items 2,3,5) demonstrated lack of engagement, with PPC metrics varied from 45% to 70% in this cycle.

5.3 Cycle 3 Domgas 2 (DG2) July – September 2014

Figure 5:11-Scaffold on DG2

Figure 5:12- Vent lines on dryers

This project was undertaken in an outage of the Domgas 2 train, which supplies gas to the domestic market (figures 5:11, 5:12). This and Domgas train 1 supplies a high proportion of the Western Australian market. The work scope was an almost exact replica of that undertaken on the DG1 outage, involving the replacement of valves and pipework with the associated insulation and cladding scope. The EPCM contractor was EPCM #1 with the IC contractors, IC #1 and IC #2 completing the inspection scope.

5.3.1 Constructing and Planning

The WWP had been discontinued after the DG1 outage. Following discussions with the EPCM management team it was proposed that it would be reinstated and in the process become a standard meeting. This would be carried out on a set and agreed day and time with the WWP sheet populated in advance from the CPM schedule. It was clear upon analysis of the previous cycle outcomes that the LPs struggled with the process of calculating the PPC value. This was an issue not revealed by literature or previous experience and again demonstrated the need of a structured implementation approach. With this structure in place, LPs are continually guided and mentored through the implementation process. Part of the structured approach was the use of the single sheet (figure 5:10) providing the main aspects and expectations of the WWP is a concise way to ensure a standard easily understood message was consistently relayed to the LPs.

Lessons from cycle 2 informed the planning on cycle 3. Discussion and informal interviews were used to get input and feedback from the LPs, the workforce, management, supervision and other stakeholders. The planning phase included organising meetings and discussions with EPCM#1 management and supervisors to discuss how best to re-implement the WWP meetings and organise some Team Work Design (TWD) workshops. One issue previously encountered was obtaining a common consensus on WWP meeting timings. This was a contentious issue, as there still seemed to be a perception that time spent planning was unproductive time. The researcher had to negotiate a period during the week where work was at its least busy. After several conversations and negotiations like the one below, a consensus was reached that the most suitable, time causing least disruption would be Sundays and Wednesdays at 1:30pm.

Whilst EPCM management provided support, including attendance at the WWP meetings, less engagement was observed from the IC site management team. To address this, the researcher held several meetings with their managers. Furthermore, participant observation revealed shortcomings with the quality of CPM reporting and forecasting and with supervisory understanding of this reporting. This was an important insight as the CPM scheduling was being used to inform weekly production planning:

Mon 5:55 am

Temp; 28ºC and sunshine

Spoke to the scaffolding supervisors on LNG1. There is a lot of confusion with the schedule. Work is being added all the time that could have been done much more easily at an earlier point. This is becoming very confused and the supervisors find the schedules impenetrable. (CON 5: lack of knowledge).

In conclusion, cycle 2 demonstrated the importance of maintaining clarity and strict structure in the organisation of the WWP meetings. Shortcomings were also demonstrated with the quality and general understanding of the CPM schedules, which influenced the effectiveness of the WWP. In addition, whilst the EPCM managers demonstrated strong engagement, it was apparent that the IC managers were less engaged. Lessons learned in this planning phase was used to inform implementation in the “taking action” phase as described below.

5.3.2 Taking Action

Acting in cycle 3 included the continued use of the DH and the WWP as well as the introduction of pull planning.

5.3.2.1 The Daily Huddle (DH)

The following is a description of the cycle 3 DHs with analysis on the outcomes observed. The DH had continued in the researcher's absence whilst away on R&R. It was apparent that the DH set the time that supervision and the gangs arrived on site. However, it still was taking a considerable amount of time for people to sign onto permits and get to the work fronts as evidenced by the following DH.

> *Wed 7:35am -7:42am*
>
> *Temperature; 28º C and sunshine*
>
> *Meeting: DH, 14 No*
>
> *Supervisors' superintendents from EPCM #1 and IC #1. No management or SC staff. Two from IC #2. EPCM 07 led this. Good leadership shown, got everyone involved.*

The following actions were observed on site following the DH.

> *8:10- Still many people milling around the humpy. Some people involved in signing permits.*
>
> *8:20- Most people at workface but only setting up the fencing and bunting*
>
> *8:30- Most people now at work but still 4-5 at the humpy and at the stores*
>
> *8:50- Everyone at work (DH 4: embedment setback).*

The above demonstrated poor worker synchronisation with resultant poor workflow. When the DH started even five minutes late, there was a ripple effect observed with the workforce in some cases 50 minutes late to work fronts. However, there was also evidence of evolving practice. This was where one person took control, asking each attendee to give a quick précis of what their crews were doing on the upcoming day. People also started making commitments to help other supervisors out with spare labour resources.

Nevertheless, the quality of the DH was still variable in this cycle. It was clear, as noted in the previous cycle, that the timing and success of the DH had a knock-on effect on the day's work. A good interactive DH, with people turning up on time resulted in crews starting appropriate work effectively in good time. The opposite was true when people arrived late.

5.3.2.2 Weekly Work Plan (WWP)

The WWP continued in cycle 3, informed by previous lessons learned. The implementation was the first where the supervisors started to demonstrate an understanding of the concept of production planning. The change in the usage of the language was also significant. Despite extremely busy workloads, the EPCM site managers continued to attend WWP meetings, again incisive and articulate in describing the reasons the last LPs should engage.

The implementation of the WWP continued with production planning undertaken for both the Domgas 2 (DG2) works and the LNG 1 concurrent preshut down work. The LNG 1 pre-shut work, involved the erection of access scaffolding for the upcoming shutdown. The EPCM site manager attended the first meeting. Again, he was supportive, explained what was involved and expected and why the meeting was an important weekly event. This meeting was significant as it was one of the first times that people started talking about making commitments. Newer people involved in the WWP were drawn into the dialogue as the production planning was undertaken.

> *Tuesday 1:30-2:00*
>
> *Meeting: WWP meeting*
>
> *Attendance: EPCM 09, IC 01, IC 04, IC 06, EPCM 01*
>
> *EPCM 01 gave a talk on what was involved in the WWP and IC 01 added to this description. The teams were split into DG2 and LNG1, who went to separate rooms. IC 01 are beginning to understand constraints and were explaining this to the group. Decomposing the teams into units with good interaction between the WWP. IC 01 was asking people if they could commit to the activities. IC 04 (DG1) came back and checked that the plan was OK, but there was a bit of confusion about the concept of constraints (WWP 7; use of language).*

The following WWP meeting was held at the weekend with some positive outcomes:

> *Saturday 1:30- 2:00pm*
>
> *Temp; 30º C and sunshine.*
>
> *Meeting WWP:*
>
> *WWP meeting with IC 01. IC 09 was off today and so couldn't get an update of the completed WWP. Good discussion; everything is practically complete on DG 2 pre-shut.*

The WWP meeting will now be held on Sundays and another one organised for Wednesday before the shut. (WWP 8; engagement).

However, this successful outcome was followed by a WWP meeting, which proved less successful. The outcomes are described below:

Sun 1:00 pm – 1:30pm Temp; 27º C and sunshine.

Meeting; WWP

Present: IC 01, IC 03, IC 04, IC10, IC 14

The WWP for DG2 did not go smoothly. There was a split down the middle with the welding supervisor failing to attend even though his work was on the critical path. The mech supervisor didn't want to be involved and failed to complete a WWP for the upcoming 4 days. These two new supervisors have caused the process to become destabilised (WWP 9; embedment setback).

The above demonstrated where the WWP meetings could become destabilised when a new LP failed to engage for whatever reason. Sometimes this was not from a lack of interest, but a lack of planning expertise coupled with the expectation that the production planning process would be daunting and beyond their capabilities. The following is reflection on these setbacks

Reflection

The introduction of new LPs seemed to destabilise the process. It was obvious that some of the new LPs were struggling to understand the concept of planning itself. This was the first time that I began to understand that this lack was one of the main reasons for the patchy implementation of the WWP. This was quite an epiphany and was something I had not considered before. Previously I expected that supervisory staff could plan their work and to be able to read a Gantt chart. This did not seem to be the case here (MEMO 7: embedment setback).

Due to the lack of success of the Sunday meeting a further meeting was scheduled for the Monday with some time spent explaining the procedure and expected outcomes.

Mon 2:00 pm.

Meeting: WWP with IC 09, IC 10.

The LPs seem to be struggling to get the WWP commitments sorted. This should have been completed but have still to have it done today. Discussion with IC 10 (welding supervisor). He hasn't completed the WWP either and seems unwilling to do this. Says he's too busy. He hadn't attended the WWP on Sunday and getting a lot of push back from him (WWP 10: embedment setback).

These outcomes were poor, still demonstrating the destabilising effects of new inexperienced LPs. This was a difficult stage of the research, demonstrating the severe challenges encountered that had to be overcome. This is reflected on below.

Reflection

I had to spend a lot of time and effort to get support from SC supervisors and the EPCM management. I felt that if things were not stabilised soon then events would spiral out of control and all the previous work and the early success would have been wasted. Yet again the support supplied by SC and the EPCM contractor proved invaluable, with resulting positive outcomes. *(MEMO 8: embedment setback).*

Some of the resistance ensued from the pressure of a busy workday, including meeting and reporting requirements that supervisory staff had to deal with. The following outcome demonstrated not only the importance of getting support from management but also the effect mentoring and support from the peer group can have at the WWP meeting. The supervisor initially resisted involvement in the WWP meetings turned around his progress. Before taking part, he was behind schedule with a scope that was on the critical-path, having to make do with less resources than planned. Despite this, his teams of welders succeeded in completing the work ahead of schedule.

Sunday 1:00- 1:30 pm.

Meeting: WWP.

Attendance: IC 12, IC 01, IC 07 (planner), IC 06, IC 05 (supervisor paint and blast), IC 10 (welding supervisor), EPCM 01.

This was a good production planning session with IC 12 (IC #1 site manager) attending. IC 10 the welding supervisor demonstrated engagement and appeared more comfortable with the meeting process. IC 01 and the rest of the group offered coaching and support.

Scott is on schedule despite having only 2 out of 6 welders available. (WWP 11; informal leader, engagement).

The following section describes implementation of a Team Work Design (TWD) workshop.

5.3.2.3 Team work design (TWD) implementation

The second workshop was not as effective as the earlier one in cycle 1. This one was undertaken with scaffolders working on the pre-outage work for the upcoming LNG1 outage.

The following are notes following the implementation of the second TWD workshop

Monday 1:00 pm – 2:00 pm

Meeting: TWD workshop

Attendees: SC 02, SC 11, IC 14, IC 10

Some points were developed and need to be chased up on – see the filled-out sheet

Need more structure around these meetings to explain what is involved and to get the message across. Need to develop and agree the points that are going to be discussed prior to the workshop itself.

Post meeting note:

Spoke to EPCM 10. He can see the merits and possibilities with the process but thinks it might be more beneficial to escalate this up to supervisors PM's and designers, (WS 2. embedment setback).

Reflection on the TWD workshop outcomes

I felt that there had been a particularly poor outcome from the workshop. On the surface, it was successful in that issues were raised in the workshop that was taken away for resolution or a reply if no resolution was forthcoming.

The following issues were raised which were then resolved and the following details sent out to the participants

Simplification of permitary:

There is currently an ISSOW simplification team looking at ways to make the permitary simpler and achieving what it was set up to do in the first place. Currently this group are working on this and have also sent around a questionnaire to SC and contractors to see what people's view are on the matter

Cameras:

It is possible to get a permit for IS camera if you need to have one with higher resolution. Firstly, check the list of existing cameras already on site to make sure there is not already a suitable one on site. If one is not available and there is a good reason for needing an improved camera that those already available, a request form is available.

However, I felt that whilst these issues may have been raised and resolved, resolving these issues did not fulfil the raison d'être for the meeting. It should be about using the gathered expertise and knowledge to develop continuously improving standard work, not a discussion of a load of unrelated "stuff". In future, I would need to be much clearer in describing what the purpose of the workshop and guide the participants towards achieving those goals. I also had much more success when the workshop followed on from several iterations of the LPS and then engaging the LPs in a workshop. I had no previous interaction with this group.

The boundary object used here was the form used in the cycle 1 (figure 5:5). This on reflection seemed to be limiting, where a white board using post it notes would have opened the discussion more. (*MEMO 11: embedment setback)*

The workshop above, forming the "plan" stage of the TWD process, was not a success, as described. More positive outcomes were observed from the implementation with the STIPS teams, with LPs in these teams willing to engage, following the early success of the WWP implementation. The later workshop was more disjointed. Also, no outcomes from the workshops could be tested in first run studies (FRS) to develop standard work. This was a limitation, as the expectation of those involved in the workshops was that the ideas would be trialled on site.

.

5.3.3 Events descriptions and outcomes

- Red - Improvement required
- Blue - Some visible improvements/ some engagement
- Yellow - Improvement in Practice
- Green - Good practice
- Purple - Evolution in practice

Cycle 3- Implementation of Daily Huddle on Domgas 2 (DG2)				
	Date	Time	Event and Outcome	Issues raised/resolved
1	Mon 28th July	7:45 - 7:50 am	Good interaction. The DH has carried on from DG1.	Demonstration of the positive effect of client team (SC 12) support.
2	Tues 29th July	7:45- 7:54am	Good DH. Led by EPCM 07. Good leadership as he goes around the circle asking people what they expect to achieve on the day.	Demonstrating the use of the DH to facilitate leadership.
3	Wed 30 July	7:48- 7:58 am	Late start, People including workers and supervisors arriving late. Late start on workface; 8:50 in some cases.	Demonstrating how a late start of even 10 minutes resulted in delays in work itself starting.
4	Thur 31 July	7:43- 7:48am	Good DH. People at work face by 8:00.	
5	Fri 1st Aug	7:43- 7:48am	Good DH. Well led by CD. Introduced a new initiative by asking what the main H&S points were for the day.	Demonstrating evolution of the tool.
6	Tues19th Aug	7:10- 7:14am	These are going well. This also used by EPCM 13 (EPCM #1 H&S) to get safety message out.	The DH now tends to start 5 minutes earlier than schedule.

Table 5:6-Cycle 3 DH outcomes

Cycle 3- Implementation of WWP on DG2				
No	Date	Time	Event and Outcome	Issues raised/resolved
1	Tues 5th Aug	1:30- 2:00 pm	First WWP sessions on this trip. One carried out for DG2 (pre-shut) and one for LNG 1.	Use of language.is an indicator of engagement and understanding.
2	Sun 17th Aug	1:30- 2:00 pm	The WWP for DG2 went quite badly. There was a split down the middle with the welding supervisor failing to attend and the mechanical superintendent failing to engage in contrast to the experienced LPs present.	Demonstration of destabilisation when inexperienced LHs introduced to the WWP.
3	Wed 20th Aug	10:30- 11:00 am	Good engagement from the welding supervisor (work on critical path). Well mentored by IC 01. Some lack of engagement from IC #1 mech supervisor and no engagement from superintendent.	Shows how the WWP can highlight LPs who struggle to plan and how disengagement will destabilise the process.
4	Wed 20th Aug	10:30- 11:00 pm	Well organised by IC 02. IC 06 proposed that a block and tackle be used to lift pipe 23004 into position instead of using the crane. It was agreed that this would be simpler and quicker.	The night shift uses the WWP as an opportunity to discuss the work and the interfaces.
5	Sun 24th Aug	10:30- 11:00 am	Generally, a good WWP. Good engagement by welding supervisor).	Demonstration of the clan culture with support and mentoring evident from informal leaders.
6	Sun 24th Aug	10:30pm - 11:00	The new form populated by the IC #1 planner from P6 was long and complex and the welders and mech supervisors did not manage to populate the WPP properly.	Demonstration of issues with the CPM schedules.
7	Wed 27th Aug	10:30 am	Very poor WWP. Hardly anyone turned up. The regular LP's had good reasons and gave their excuses, but the supervisors on the critical path (mechanical) failed to provide reasons. The EPCM #1 planner was unable to populate the activities in the WWP from P6 because of a 24-hour lag on P6 reporting.	Issues with CPM schedules.
8	Thur 28th Aug	10:30- 11:00am	Back on track. WWP attended by all relevant supervision, apart from mech superintendent. Input from mech supervisor.	The PPC's are still mostly 100%, suggesting that crews are not being stretched.
9	Sun 31 Aug	1:00- 1:20pm	Attendance from all including mech superintendent, good positive input from him and seems to be getting to grips with the process.	PPC is still at 100%. This will need to be the focus for future WWP meetings. May need some more focus on coaching.

Table 5:7-Cycle 3 WWP outcomes

Cycle 3- Implementation of TWD on Domgas 2 (DG2)				
	Date	Time	Event and Outcome	Issues raised/resolved
1	Mon 25 Aug	1:00 pm	Poor outcome.	Recommended that the TWD participants have prior involvement in the DH and WWP with the workshop organised in a focused manner.

Table 5:8- Cycle 3 TWD outcomes

Summary

The analysis of cycle 3 produced several findings to be incorporated as lessons learned in cycle 4. An analysis of coding and tables 5:6 and 5:7 demonstrated the variable and sometime poor outcomes witnessed from implementation of the DH and the WWP. The DH became part of the daily work approach but it was clear that the usage would not automatically transfer from project to project, even with the same staff and workforce on each project. This was made evident in this cycle when the SC construction superintendent had to challenge the EPCM contractor to restart the DH (table 5:6: item 1). Again, this demonstrated the important role client management play in ensuring sustainable embedment. There was also further confirmation of evolution of practice (table 5:6 item 5). This was initiated by one of the superintendents and involved the introduction of a discussion on the key H&S issues for the day. The timing of the DH was again an indicator of how the working day would unfold. If people attended on time and were engaged (table 5:6: items 1, 2, 4) the workforce were synchronised with work starting quickly and efficiently. People arriving late to the DH was a portent of a poor start to the mornings work (table 5:6 item 3).

The summary of the implementation of the WWP in cycle 3 demonstrated the ongoing challenges in establishing stability in the implementation of this tool. The lack of consistency in meeting timings demonstrated poor engagement. The LPs still chaffed at the disciple required, preferring to be “doing” rather than planning, referred to by SC 02 as “being too busy cutting wood to sharpen the axe”. A lack of scheduling knowledge by many of the supervisory staff was demonstrated. In addition, the introduction of two or more new LPs destabilised the process (table 5:7 item 2). There was also an early perception that the WWP was a method to hold people to account and apportion blame for “non-performance”. It took some time to re-stabilize (table 5:7 items 4, 9). Again, the EPCM management and informal leaders were the people who provided the leadership and commitment in this process (WWP 11) with the use of language signifying engagement levels (WWP 7). In addition, night shifts, with fewer managers present had a less stressed atmosphere than days. The LPs were more harmonious and engaged in more discussion and banter at the WWP meeting, challenging work issues and developing good work practice (table 5:7 item 4). An initiative to introduce some alignment between the master programme (P6) by populating a spreadsheet with scheduled activities (table 5:7 item 7) was not successful. These highlighted shortcomings in the master scheduling and pointed to some of the reasons as to why the LPs were having difficulty planning in the WWP meetings. Another reason for difficulties appeared to be the complexity of the schedules (CON 5). This cycle demonstrated the difficulties encountered in the implementation of the WWP, uncovering issues such as the lack of understanding of basic planning among the workforce. Apart from limited references to this phenomenon in literature (Galloway 2006) there is little evidence of a widespread appreciation in the industry of the issue.

The implementation of the TWD had poor outcomes, primarily due to participants without prior experience of the lean tools and to a poorly defined scope in the work shop implementation.

5.4 Cycle 4 LNG1 preshut scope August – September 2014

Cycle 4 was implemented on the LNG 1 pre-shutdown scope of works. LNG 1 was one of the first trains constructed at KLE, with construction started in 1986. At 30 years, old, it has exceeded its design life, but with ongoing refurbishment is expected to continue in operation for an extended number of years.

Figure 5:13- Scaffold to exchanger

Figure 5:14 completed scaffold access

The work consisted for the most part of the erection of scaffolding for the LNG 1 shut-down (figures. 5:13, 5:14). The LNG 1 shutdown was a major scheme lasting 29 days with 800 workers on days and equal numbers working nights. The shutdown involved the refurbishment of pipework, vessels, and valves. The work itself started later than DG2 and then ran in parallel with DG2 scope. The EPCM contractor EPCM #1 and the IC contractors' IC #1 with IC #2 undertaking the inspections, worked on both with an interchange of personnel between work scopes. The DH was implemented on the LNG1 pre-shut down work, with work undertaken to prepare the LNG 1 train for its shutdown at the end of October. Work included scaffolding, installation of fall object protection and the removal of cladding as required. IC #1 and IC #3 erected scaffolding for the KLE group, with EPCM #4 erected most the scaffolding for the Karratha Major Shutdown (KMS) group.

5.4.1 Construction and planning

Lessons from cycle 3 were applied in this cycle, including that the introduction of too many LPs, unfamiliar with planning concepts, quickly destabilises the WWP meetings. In addition, it was demonstrated that issues with the CPM schedule presents a barrier to the successful implementation of the WWP. The construction phase, as always was informed by discussion with previously engaged and new stakeholders. The planning cycle was less involved than on the other works. Practically the same supervision and same crews undertook this cycle as cycle 3, with some additional scaffolding supervisors and scaffolding crews as discussed.

5.4.2 Taking Action

5.4.2.1 The Daily Huddle (DH)

This DH took some time to become re-established. This was in part due to the introduction of some new supervisory staff on this scope of work with no previous exposure to the tool. The slow response and the eventual reestablishment of the tool is described below. As noted the continued engagement of EPCM management facilitated understanding and a relatively fast embedment of the DH.

> *Wednesday: 7:55- 8:05 am; Temp; 28º C and Sunshine*
>
> *DH on LNG 1. This was very disjointed and it took a good while to get everyone together. People were unsure of the expectations. EPCM 01 was present and then explained what*

the expectations were. This was IC 05's first time to lead and he was also a bit unsure, but did a good job under the circumstances. EPCM 01 waylaid an EPCM #4 superintendent who gave a quick description of their work to the group. EPCM #2 (another EPCM contractor) leading hands and supervisors, their interest piqued, also came across to see what was going on. Following late start last crew at workface at 8:50 (DH 5: evolution of practice).

The DH carried on as part of the daily routine. It had become the "way we do things".

Date: Friday 7:45- 7:50am; temp; 31º C and sunshine

Meeting DH

This was a good DH. Led by IC 05. Stood in the middle of the group. EPCM #4 (not part of the research) were involved in this. Crews got to work relatively quickly with last crew on workface by 8:20. (DH 6: engagement, synchronisation).

After some initial inertia, the DH became embedded relatively quickly, particularly in comparison with the previous cycles. The DH ran in parallel with the WWP, with implementation outcomes described below.

5.4.2.2 Weekly Work Plan (WWP)

This was the first time that two WWP meetings for two different projects ran simultaneously. As in previous cycles, there was positive input from the EPCM site management, who attended the WWP meetings, outlining expectations and how the process could assist in workflow organisation. The use of language was striking, with the WWP co-ordinator now beginning to use the term "commitment "for work last planners (LPs) promised to complete in the upcoming week.

Tuesday 1:30-2:00pm

Meeting: WWP meeting

Attendance: Mark, EPCM 09, IC 01, IC 05, IC 09, EPCM 01

EPCM 01 gave a talk on what was involved in the WWP and IC 01 added to this description. The teams were split into DG2 and LNG1, who went to separate rooms. IC 01 is beginning to understand the concept of constraints and conveyed this to the group. Good interaction between the LPs. The WWP meeting the researcher attended was producing production *planning for LNG 1. IC 01 was asking people if they could commit to the activities IC 05 (DG2) came back and checked that the plan was OK, there was still a bit of confusion about the concept of constraints.*

The Scaffolding LP IC 09, committed to an ambitious amount of work on LNG 1 and before he could fully commit, said he would have to get the commitment from his leading hands. I have never seen this practice before and there is no evidence in industry literature of this happening. This is an interesting development. (WWP 12; use of language, evolution, synchronisation).

This was the first time the researcher had witnessed a LP explain that he needed commitments from his leading hands before he could commit to the activities proposed at the WWP meeting. He was operationalising the maxim that you cannot make commitments for someone else and he also noted that this would make life a lot easier for him as this process ensured early involvement of the leading hands on planning layouts and materials organisation requirements. The WWP meetings continued with the following as an example:

Sun 1:00 pm-1:30pm; Temp; 27º C and Sunshine

Meeting; WWP

Present: IC 01, IC 09, IC 06, IC 05, IC 07

This went well for LNG 1, IC 09 reported on last week's work. He said that his PPC was 50% but a check later showed that it was 75%; He wasn't included for jobs that were completed late in the period. (WWP 13: engagement).

This was one of the first times that the PPC were being consistently recorded in this range. Previously all the PPC's tended to be around the 100% level, indicating that the LP's were under-committing on expectations. It was apparent that both the scaffolding supervisors on LNG 1 who were acting as the LPs had grasped the concepts very early on and were comfortable with the process. Following some conversations, it transpired that they had worked in the UK construction industry where they noted that there was an expectation that supervisors should plan work on a weekly look ahead basis. As discussed in cycle 3, very few of the supervisory staff possessed this knowledge, an issue reflected on as follows.

Reflection on the level of planning abilities

I had reflected on the reasons why there seemed to be such difficulty in getting the WWP embedded as part of the way of doing things. I had taken it for granted that all supervisor staff would be familiar with short term planning and can read a simple bar chart. This did not appear to be case with a large proportion of the supervision who found it a stressful and intimidating process trying to understand the primavera CPM scheduling being used on the refurbishment scope of works. (MEMO 9; lack of training)

Care was taken that the LPs understood the mechanics of planning in general and the WWP. The researcher also continued to use boundary objects such as WWP advice for implementation (figure 5:10). The WWP meetings then started to gain embedment.

5.4.2.3 Pull Planning

Pull planning completes the LPS suite of tools where a pull approach is used to develop longer term planning, typically in a three to four month look ahead in a project. This approach utilises the knowledge, experience and insights of the decision makers involved in upcoming work scope. People involved in this planning exercise may include the project management team, project engineers, superintendents and supervisors. This is the most time consuming and difficult tool to implement and it took a considerable amount of work and effort to get to this point.

The researcher organised a meeting with EPCM and SC management staff to describe the mechanics of pull planning and potential outcomes. People were generally keen on the idea in principle, but found the concept of the reverse pass scheduling a difficult one to grasp. They also felt that the process would be too time consuming. Following this feedback, the researcher organised a workshop to demonstrate the concepts.

> *Sat 1:00 pm Temp; 27º C and Sunshine*
>
> *Meeting: Pull planning session*
>
> *Present, EPCM 02, EPCM 05, EPCM 07, IC 01, and IC 08 (IC 01 planner) EPCM 03 (planner).*
>
> *This went quite well. I rolled the sheet of A1 paper out and showed everyone how the planning worked, there were some questions from EPCM 05 as to what level from the*

schedule the pull planning would use. He was very keen on the pull planning, saying that it would give him insight as to what was required to happen out on the field. I started the planning and people were getting involved in it and quite keen. The consensus was that it couldn't be used on the DG 2 shut now or the LNG 1 but it would be useful to use on some of the upcoming smaller scope (WS 1.1: engagement).

However, despite the enthusiasm, attempts to follow up and organise some actual pull planning workshops proving futile. Time availability was the main reason given for failure to continue.

5.4.2.4 Team work design (TWD) implementation

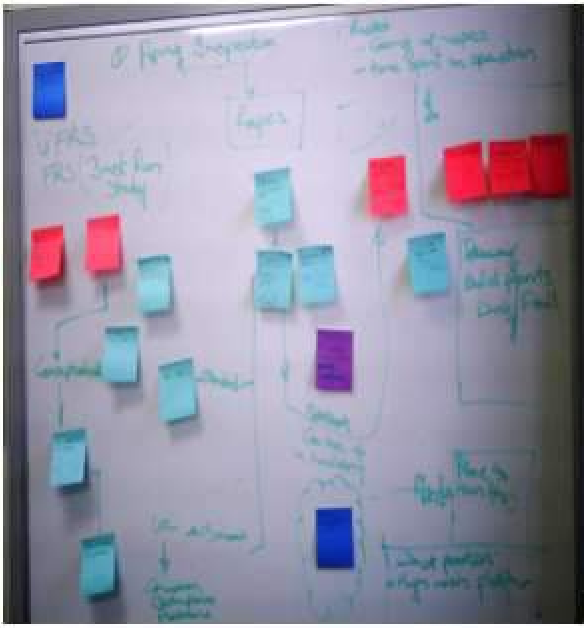


Figure 5:15- rope access **(**DOC 12**:** evolution of practice**)** **Figure 5:16** scaffolding access (DOC 13: evolution of practice)

There were further attempts to implement the TWD tool in this cycle. In one instance 6 inspectors attended a workshop, using the boards above to develop ideas for standard work development. Two work types were addressed which was inspections off scaffolding and inspections from rope access. Several ideas were proposed which included improved collaboration with scaffolders to ensure locations were correct and use maximised, increased use of models, improved bags to carry tools and drawings. The use of the white boards (figures 5:15, 5:16) aided better interaction than witnessed in previous cycles. Again, the participants engaged, with innovative ideas discussed. However, there was no opportunity to test the proposals in PDCA cycles to develop standard work.

5.4.3 Autonomous development of Practice

One dominant strand throughout the primary research was the autonomous development of practice by the workforce, including supervisors and management. An example was the development of a strategy to act against a particular waste, “waiting” waste, one of the eight wastes. This occurred at the start of shifts where delays were observed as crews started work, due to uncertainty of worker and task availability on refurbishment scope. These delays could last up to 2 hours. Worker availability uncertainty was caused in part to changing rosters caused by the fly in fly out (FIFO) regime. Delays also occurred as teams waited for permits to be taken out from the ISSOW focal point by the team performing authority (PA). This is a team member tasked with signing out the permits before work starts. Observation revealed the development of a sheet by the workforce addressing this potential waste (figure 5:17). This briefing sheet was developed entirely by supervisors and consisted of an A4 sheet, prepared daily, populated from the WWP. This addressed waiting time by the pre-allocation of tasks and crewmembers to crews. Its daily production was a collaborative process by LPs and the development was noteworthy for several reasons. A literature search has not demonstrated workforce led autonomous development of lean tools. The supervisors developed this tool in an intuitive manner, to act against one of the eight lean wastes: waiting. This happened in the mornings where delays occurred as supervisors assessed the upcoming day’s labour and work availability. The briefing sheet addressed all these issues using a very simple format to highlight relevant data and information before work started. This was innovative practice, initiated and owned by this workgroup and was an effective and simple approach.

AGC-KLE Lng-Daily Scaffold Crews - Monday-11/08/2014			
Crew	JCX	Area	%
Sila T	JCX-1192	10L	Priority.1- 95%
Eddie P	JCX-1207	10E	Priority.4
Martin T	JCX-1206	10E	Priority.5
Mark R	The above Shaded come off JCX-0040		
	JCX-0040	10E	70%
Shannon H	JCX-0220	10E-Breezeway	95% - Ply
Pradeep G	JCX-0172	Area 10B	new job-75%
Brendon R			Frame up until spading done
Paul H			
Joel K	JCX-1371	10A	Priority.2-95%
Bob R			
Heath B			
Steven P	JCX-0177	10C	Priority.3-60%
Jess B			
Corrin M			
Gary H	JCX-0242	10L	New Job-15%
Tyron			
Aron B			
Alf A	JCK-0219	10B	New Job-100%
Mike D	JCK-0231	10D	New Job
Leigh S	JCX-0007	10D	New Job
Paddy	PA		
21 Scaffs + 1 PA-23			
X3 Supervisors			
			10C - JCX-0253-95% - Ply
			10L - JCX-1192-95% - Ply
J.F Dujardin	SICK-(Back)		10E - JCX-0220-95% - Ply
Barry M	SICK		10A - JCX-1371-95% - Ply
Darryn Dhuy	Approved Leave		
Connor D	RDO		
Troy A	RDO		
Wade T	RDO		
Dillon T	RNR		
Andrew A	RNR		
Otto S	RNR		
Shane M	RNR		

Figure 5:17- Morning briefing sheet (DOC 5: team autonomy, evolution of practice).

5.4.4 Event Descriptions and Outcomes

Outcomes

The following provides information on outcomes from the cycle using the colour coding below with the outcomes from the DH, WWP and TWD tabulated separately.

- Improvement required
- Some visible improvements/ some engagement
- Improvement in Practice
- Good practice
- Evolution in practice

Cycle 4- implementation of the DH on LNG 1 Pre-shut				
	Date	Time	Event Outcome	Issues raised/resolved
1	Wed 6th Aug	7:55-8:05am	Disorganised start. This was the first DH on LNG 1. DH leader was IC 05 EPCM #01 site manager attended the DH.	Important to Identify leader or informal leader that organises the DH. Ten-minute delay in start with work crews getting to work fronts up to 50 minutes late.
2	Thur 7th Aug	7:45-7:50 am	Good DH. Also, included EPCM #04 and IC #02. This was confidently lead by IC 05.	Other contractors being pulled into the DH.
3	Fri 8th Aug	7:45-7:50 am	Good DH. Also, included EPCM #04 and IC #02.	Other contractors getting pulled into this event
4	13 Aug	7:52-7:57am	Very poor with only one leading hand present from IC #1. Supervisors from IC #1 were trying to sort out permits at the office.	This delay had a knock-on effect on the starting times for crew.
5	Fri 15th Aug	7:45-7:50 am	DH include ops, EPCM #02 supervisor, IC #02, EPCM #04 two IC #1 supervisors.	Other contractors being pulled into DH.
6	Tue 19h Aug	7:43-7:46 am	DH including IC #02 another IC contractor.	This DH has now settled into a routine.

Table 5:9 - Cycle 4 DH outcomes

Cycle 4- implementation of WWP on LNG 1 Pre-shut				
	Date	Time	Event and Outcome	Issues raised/resolved
1	Tues 5th Aug	1:30pm-2:00	First WWP meetings on this cycle. One carried out for DG2 (pre-shut) and one for LNG 1.	Demonstration of use of language to signify change and LP seeking commitments from his leading hands before committing (PPC 100%).
2	Sun 17th Aug	1:30pm-2:00	This went well for LNG 1, IC 04 reported on last week's work and completed the WWP later in the day.	PPC 75%. This is the first PPC that appears reliable.
3	Sun 31 Aug	1:00pm-1:20pm	The WWP reveals supervisors getting commitments from their leading hands.	PPC @ 90%. Probably a bit high but still a good trend.

Table 5:10-Cycle 4 WWP outcomes

Cycle 3- Implementation of TWD on LNG 1 pre-shut				
	Date	Time	Event and Outcome	Issues raised/resolved
1	Fri 15th Aug	1:00 pm	TWD work shop held with inspectors, Good engagement demonstrated.	Several ideas proposed which could be used to develop standard work porotypes.

Table 5:11-Cycle 4 TWD outcomes

Summary

The implementation of the DH and WWP and the TWD tool demonstrated further outcomes not identified by literature. As noted, the DH set the arrival time of the workforce at the work fronts, with actual arrival times an indicator of how quickly and efficiently work groups would start work. A lack of synchronisation with late arrival of only 5 to 10 minutes augured a poor start to the day; with some crews getting to the workface up to 50 minutes late. It was observed that when crews lacked necessary organisation and drive to get on site in time, this sense of disorganisation rippled out through the morning set-up (table 5:9 item 1, 4).

In this cycle implementation stabilised faster than in earlier cycles, assisted by the support of EPCM site management (DH 5). By consistently attending, they demonstrated the significance they attached to the DH. It did destabilise (Table 5:9 item 4) later, but stability was re-established relatively quickly as people engaged (DH 6). In addition, contractors such as EPCM #4 and IC #3, who were not part of the implementation, started coming along to the morning DHs (table 5:9 items 2, 3, DH 6). Invited into the DH on the 6th August they subsequently continued to come along to find out what each work group were doing and the potential of work fronts clashes. This demonstrated the tools ability to draw the workforce in and the merits they saw in it as a forum to access valuable information.

Observation again demonstrated that LPs with previous planning, lean or lean type experience engaged quickly. A lesson during the cycle was some LPs insistence (table 5:10 item 1) of the need seek commitments from their leading hands before they could make commitments themselves. In this, they had operationalised the concept that a person can only make commitments for himself or herself, not other people. Furthermore, the same LP led the implementation of a novel approach to counter waiting (figure 5:16). Again, this was evolution in practice instigated solely by the workforce. In addition, this cycle demonstrated a high level of workforce synchronisation. This was demonstrated initially in the DH where it quickly became established to give synchronised workflow (table 5:9: items 3, 5 and 6). Furthermore, the embedment of the WWP was accompanied by a change in language (WWP 12) where the LPs used the word “commitment” to describe promises made during the weekly WWP.

This cycle was also used to introduce Pull Planning (PP). These was some interest and engagement (WS 1.1), but this was proving the most difficult tool to introduce and embed. There was further implementation of the TWD tools. As cycle 1 engagement was observed with the prototype development stage, but with little opportunity to use these in First Run Studies (FRS).

Lessons learned in cycle 4 were applied in cycle 5 as described below. This scope involved refurbishment work on metering apparatus, undertaken by a different EPCM contractor, EPCM#2

5.5 Cycle 5 Domgas Metering (Oct-Nov 2014)

Introduction

Cycle 5 investigated the implementation, described below, on refurbishment of a section of the plant that delivers 48% of the natural gas to of Western Australia and is therefore a commercially significantly section of the plant. This work was undertaken by EPCM #2 who acted as EPCM contractor, also acting as the Implementation Contractor (IC). EPCM #2 were not previously involved in the implementation research. Work involved the removal of existing pipework and its replacement with new valves and spools to form double block and bleed valve layouts in preparation for further work to be undertaken later in 2015. The work scope also included the up grading of hardware, software and analysing systems to monitor H_2S and H_2O levels in the LNG before sale to market.

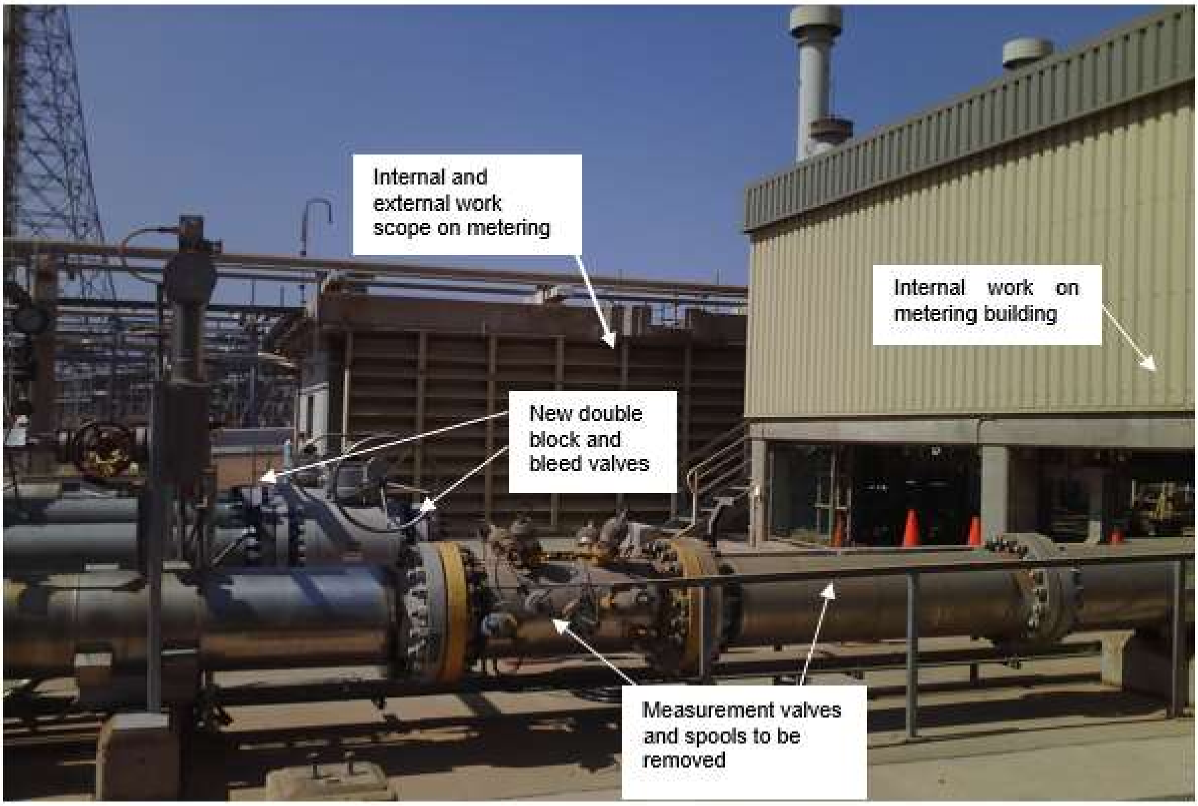


Figure 5:18- Domgas metering east (west works similar)

5.5.1 Constructing and Planning

Domgas metering was a further project with the DH altered to incorporate the information boards (figure 5:19) developed by the SC continuous improvement (CI) team on previous shutdowns.

Figure 5:19-The PI board

After discussion with the KLE SC Continuous Improvement (CI) champion (SC 11), it was agreed that the board (figure 5:19) be used as a focal point during the pre-start daily DH. There were several reasons to do this. This board was an adaption of a similar board that had been used successfully on earlier major shuts. The DH incorporated the H&S pre-start, quality and schedule. The work day started at 7:00am (10 hr day) with the performing authorities (PAs) coming in to work at 6:30am to get permits signed off.

The early introduction and explanation of the lean approach was progressed differently. In this cycle, a standardised 10-minute presentation was used to describe the main principles of lean construction. Previous examples of some successful implementation of the WWP at KLE were used to explain and generate some discussion around the implementation expectations.

5.5.2 Taking Action

5.5.2.1 The Daily Huddle (DH)

The DH used the white board (figure 5:20) as the focal point for the prestart discussion. Instead of conducting the health and safety prestart and the smart start exercises in a separate location remote from the work, these events were now incorporated into the DH. This ensured that the working day started with communication of a common message on H&S, quality and schedule status update and a look ahead for the upcoming day. The LPs and leading hands reported on the previous day's progress and then outlined projected work and predicted percentages complete for the upcoming day. Initially, the supervisory staff tended to be rather blasé about the concept of making progress commitments. However, the activity was taken more seriously, when it was realised that these commitments were being made in front of peer groups, with people then held to account by those very groups. Following the introduction of the DH and the WWP the researcher convened a look ahead planning workshop described below.

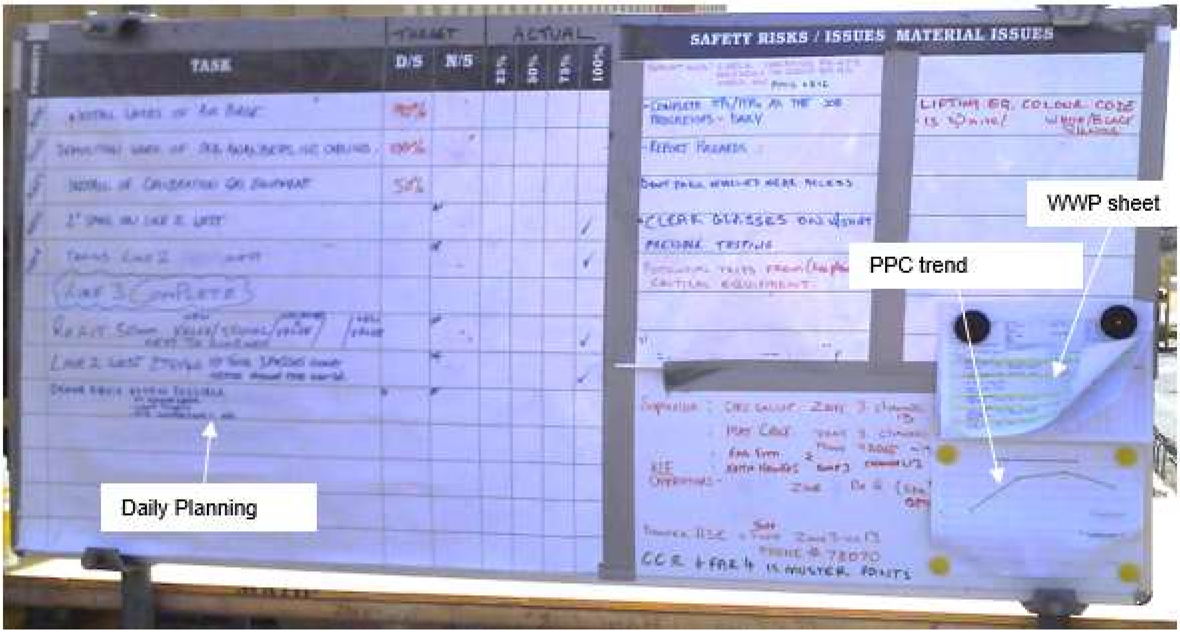


Figure 5:20- White board at Domgas metering DH (*DOC 6: evolution of practice)*

5.5.2.2 Weekly Work Plan (WWP)

The EPCM contractor used the WWP meetings on the Domgas metering contract. There was early and positive engagement by their LPs who arrived at meetings in time, having the CPM primavera schedule at hand to refer to. The site coordinator would consistently send out a scanned copy of the WWP to stakeholders following the meeting.

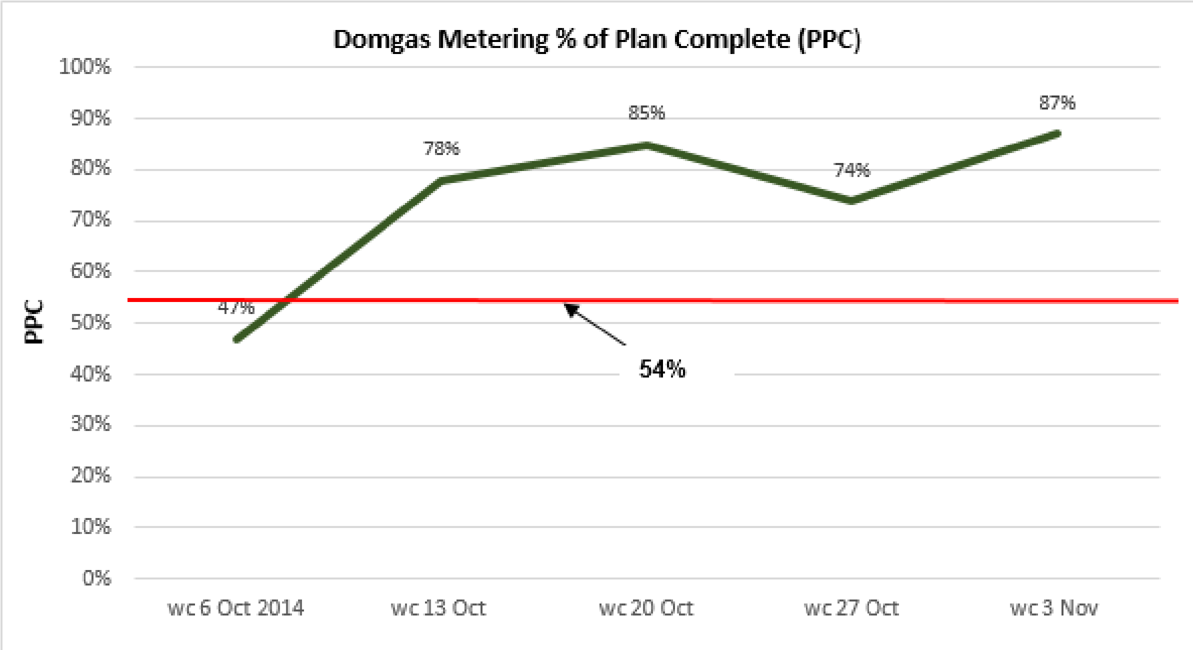


Figure 5:21-PPC Trend (DOC 7: observable tool impact)

There was a quicker uptake observed in the implementation of the WWP, in a large part due to the implementation of lessons learned in the previous cycles. The concepts were introduced to the LPs using presentations, which included examples of good practice on the previous cycles. The PPC graph above (figure 5:21) stabilised at around 80% with a 25% productivity improvement achieved, where the red line 54% is the normal construction PPC level achieved. Work scheduled for 20 days was completed in 15 days. There was a similar improvement in productivity in a subsequent project on SUB 1 (substation 1) where the lean tools were also used. The implementation of the WWP was smoother and subject to faster engagement than witnessed on any previous cycle apart from cycle1.

5.5.2.3 Pull planning:

The WWP meetings highlighted the CPM issues and so the researcher could set up a pull planning workshop with common consent. This included LPs and other decision makers including SC, EPCM and IC supervisory staff. This was the first time that a complete pull planning session had been implemented. Whilst the workshop itself deviated from the recognised pull approach using post-it notes it did produce some positive outcomes. The key decision makers planned the sequence of a job, arriving at a common understanding of scope, to develop opportunities and remove constraints. The first session lasted 4 hours on Thursday 30th Oct with a further 4-hour session including the EPCM #2 planner on the 31st Oct 2014. The planning was used to rework the existing primavera shutdown schedule and develop a logical schedule with flow. This exercise produced a reduction in total schedule time from 18 shifts (9 days) to 14. The work was then completed in 10 shifts.

However, whilst this planning session produced some positive outcomes, it could not be described as pull planning, where the re-scheduling was eventually carried out in the traditional push manner, with the use of post-its notes using a pull approach abandoned. This outcome is reflected on below.

Reflection on the outcome of the first pull planning workshop

The attempted implementation of the pull planning tool using Post-it® notes to develop schedule logic and flow from the existing very complicated CPM did not go to plan. Although a schedule was developed that had greater clarity and logic that the existing CPM, this was achieved with a great deal of effort, using the traditional push planning approach.

On reflection, there were several reasons for this. Firstly, the group consisted of very strong personalities, many of whom were highly experienced superintendents who had worked for many years in the industry. They were intent on carrying out the scheduling in the traditional manner they were familiar with. Secondly, the workshop needed to be more focused and organised from the beginning. The key take-away was the need to have an organised approach which includes a 10-minute presentation to get a common message across and to ensure that the workshop progressed in a predetermined manner (MEMO 10: evolution of practice).

Yet, despite the shortcomings there were some positive outcomes from the workshop. Foremost of these was the development of a schedule, more logical, with better flow than the existing master programme. These workshops continued; organised solely by the supervisory staff without any researcher input. They developed to a point where the SC supervisor (SC 14) could confirm two months later that when planning was undertaken for the subsequent phase 2 works:

> *Because the plan produced for the phase 2 works on Domgas metering required improvement, they (the supervisory staff) had to run planning sessions like the one done for phase 1. Again, they got all the participants in a room and spent ½ day rationalising the schedule. Thus, they have a good schedule that is logical and is working very well out in the field. Now they are doing what the schedule shows, which hadn't happened in the past. (CON 6: team autonomy).*

Whilst the pull planning was being imperfectly implemented, the implementation of the WWP and DH continued in this cycle.

5.5.3 Events Discussion and Outcomes

- Improvement required
- Some visible improvements
- Improvement in Practice
- Good practice
- Evolution in practice

Cycle 5- Implementation of DH and WWP on Domgas metering				
	Date	Time	Event and Outcome	Issues raised/resolved
1	Mon 6th Oct 2014	1:30- 3:00pm	First WWP. This lasted 1½ hour. Good interaction. Need to get LPs to make commitments rather than being told what to do.	Allow a longer period in future for the first WWP meeting. This had been only scheduled to last a ½ hour.
2	Monday 13th Oct	1:00 pm -2:00	Second WWP with 48% PPC.	Highlighted issues with labour resourcing levels.
3	Wed 15th Oct	7:00 - 7:30am	First DH using board on site: This went well. There was some transfer and evolution of practice from LNG 1 with allocated of individual crews to work fronts.	Some areas need improvement. People need to speak up a bit more and the huddle needs to move in closer to the board.
4	Thursday 16th Oct	7:00 - 7:30am	DH: The superintendent leading (IC 14) is getting people to commit to a work forecast. The workforce will commit to predicting what work they expect to complete over the upcoming day.	This is an evolution of practice not seen before by the researcher.
5	Monday 20th Oct	1:00- 2:00 pm	Third WWP	78% PPC achieved, with some constrains highlighted.

Table 5:12 - Cycle 5 outcomes from the DH and WWP

Summary

There were several learning events from this cycle. Firstly, there was a clear demonstration of an important aspect of the implementation, which is the interaction of people with the tools. In this cycle, clear structure was also established with the DH starting at a set time using the pre-start boards with the WWP and PPC trends displayed (table 5:12). This demonstrated an evolution of practice where an existing initiative using a prestart board was incorporated into the DH now combining H&S, schedule and quality.

Pull planning was reintroduced in this cycle and it is noteworthy that whilst the implementation did not progress to plan, the supervisory staff and workforce demonstrated team autonomy and evolution of practice (MEMO 10, CON 6) by developing a variant of the pull planning tool that worked for them. Implementation to date (including cycle 1) of the WWP demonstrated a correlation between PPC and performance outcomes. Thomas notes that:

There is limited evidence showing that productivity performance for crews with a PPC above 50% is 35% better than that of crews with a PPC below 50%. While these data are useful, this is hardly conclusive. More analysis is needed to confirm the causal link between reductions in workflow variability and improvements in project performance (Thomas et al., 2002, p.145).

The outcomes from cycle 5 above demonstrated a correlation between PPC and performance outcomes, simply measured in master schedule time reduction. These improvements were in the order of 25% once PPCs consistently trended at 80% levels. Notwithstanding this, more quantitative analysis needs to be undertaken on many more implementation cycles to establish the causal vector. In this cycle, the LPs cooperating in quickly implementing the WWP with consistently high PPC values achieved, correlated with performance improvements. Similarly, in the pull planning implementation participants collaborated to produce their own pull planning variant, which produced ongoing positive outcomes.

5.6 Cycle 6 Pull Planning Workshops and Inspection Scope (Jan- March 2015)

This cycle involved the ongoing implementation of the DH and WWP on inspection scope of work and pull planning workshops for upcoming work scopes in the design stages. Pull planning is one of the LPS suite of tools. Here decision makers attend workshops, collaboratively developing production planning. The period planned is approximately 4 months into the future, but can be adjusted as required. Attempts of implementation in earlier cycles met with limited success, where the potential was acknowledged but the process itself was generally seen as time consuming.

5.6.1 Constructing and Planning

Knowledge gained from positive and negative outcomes of the previous cycles informed the constructing and planning stage. This knowledge included the necessity of a structured approach and the need to include planners as well as decisions makers in the pull planning process. This enabled the planners to take away outcomes from the workshops, to develop logical schedules informed by the pull planning process.

A presentation to the SC managers and project engineers at the SC Perth head office in November 2014 generated interest. This was followed by an approach to the researcher by several SC project engineers (PEs) with a request to run some workshops to rationalise design and planning for upcoming work scope. A workshop was then organised at Karratha with the meeting invite included a YouTube video link (https://www.youtube.com/watch?v=5ecxE4XKrt4) (Mays 2015) with an agenda outlining workshop expectations and describing the implementation of pull planning. The workshop itself commenced with a 10-minute presentation describing the pull planning process.

The section below discusses how the lessons learned and evaluated from previous cycles were applied in “taking action”.

5.6.2 Taking Action

5.6.2.1 Pull Planning Workshop

Taking action included the organisation and implementation of two pull planning workshops for two distinct scopes of work. Pull planning is one the LPS tools, dealing with production planning over the longer term. When implemented elsewhere CPM master schedule milestones inform production planning (Kalsaas, Skaar and Thorstensen 2015). In this case, the pull planning was used to develop milestones and then a more detailed schedule. Participants included project engineers (PE), managers, planners and supervisory staff.

Figure 5:22-**LNG 1 pull planning workshop**

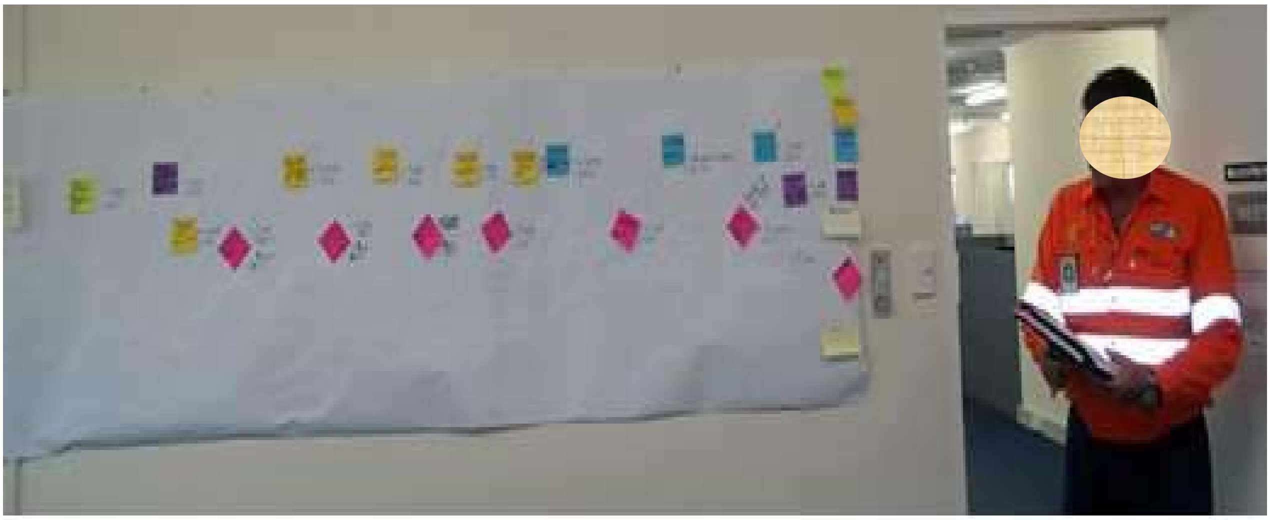


Figure 5:23-Completed pull planning board LNG 1

The work scope consisted of repeatable sub-elements, allowing the development of collaboratively agreed "templates" in the workshops (figures 5:22, 5:23). Figure 5:22 shows the workshop in progress and figure 5:23 the completed pull plan, used as a "template" to assist in the development of a CPM schedule by the planners and PEs, who took the "templates" away to develop the schedule itself.

There were other outcomes from the workshops. The first was the development of a strategy of how the project would be carried out. In the case of the LNG 1 project, work scope involved the refurbishment of pipework on three stacked pipe racks each at ten metres high, giving a total height of 30m. In the past work on such scope would start on the bottom section. It was acknowledged that this was a short-sighted approach. Whilst it was possible to achieve early positive high schedule performance indicators (SPI) and cost performance indicators (CPI) outcomes on the CPM reporting, there indicators soon revealed a downward trend when potential waste occurred where work already completed was damaged by ongoing works overhead. The agreed strategy was to always start the work on the higher levels and work down to the lower levels. Whilst slower progress would be reported in the earlier stages due to longer lead in providing access scaffolding, this early delay would be mitigated by a reduction of rework as the project progressed. This was the first time during the primary research that reference was made to the development of a work strategy.

The second workshop again involved PEs and planners who flew the 1500km journey from Perth to collaboratively develop a plan with their peers at Karratha. The scope was complex; reflected in the more complex nature of the pull planning outcomes (figure 5:24). The complexity resulted from the early work-scope uncertainty, as a high proportion of the pipework to be refurbished was insulated and subject to corrosion under insulation (CUI). This meant that there was a large degree of uncertainty as to the extent of corrosion before the work itself started on site. The strategy developed here was to start from the top, working down as before, but also to start out with a relatively high level, low detail schedule, developed further as information was relayed from site as to the extent of corrosion as the refurbishment work progressed.

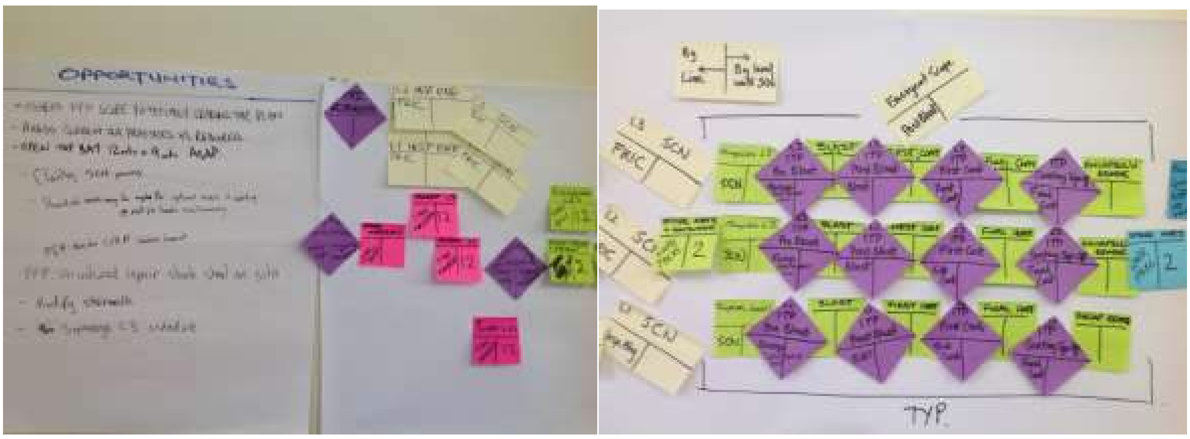


Figure 5:24- Domgas 1 workshop outcomes *(DOC 7: evolution of practice, observable impact)*

The workshops were used as a mechanism to utilise the collective knowledge and experience of the participants, collecting information on “constraints” and “opportunities” as the process unfolded. This information was recorded on flip charts and used to populate the schedule constraints sheets below.

Some of the opportunities included the identification of benefits from off-site manufacture of cladding as opposed to the use of onsite fabrication (item 4, (“opportunities”) figure. 5:25).

SCHEDULE OPPORTUNITIES	
1.	2nd coat cure time – deviation can be used as an opportunity to save time (Domgas T2)
2.	Application
3.	Fabrication on site vs Perth
4.	Pre-fabrication – cladding onsite complete before activity planned
5.	Insulation – pre-cut to size before activity planned
6.	Scaffolding delivered at job face
7.	Drop object infill at site prior to start of activity
8.	Permits – ready for issue CW/HW – battery drill / generator / compressor / equipment
9.	Efficiencies for insulation / cladding application
10.	Trip mitigation info passed onto job card

SCHEDULE CONSTRAINTS	
1.	QA/QC signoff – 2 hrs x 2 AGC / WorleyParsons resource
2.	Inspections
3.	Punch list prior to scaff demob – 2 hrs x 1 resource
4.	Fabrication of cladding / boxes and delivery of above insulation to site
5.	Applus inspection T4 generator / compressor / paint / B/P Site delivery of consumables
6.	Cure times
7.	Scaffold fit for task.
8.	Site setup / runners
9.	On line deviations for insulation / cladding removal
10.	Permits
11.	Jobcards / Rev 0
12.	Musters / rain / permit delay
13.	
14.	Bins (skips) – scrap metal / garnet / insulation

Figure 5:25- Schedule constraints and opportunities *(DOC 8; observable impact)*

Among the constraints identified was the time required for musters, rain and permitting requirements (item 12 (constraints), figure 5:25). The workshop gave an opportunity to engage the collective knowledge and experience in the room, codifying these constraints and opportunities.

5.6.2.2 Weekly Work Plan (WWP)

In this cycle, PEs and inspectors undertaking inspection scope implemented the WWP. This work involved inspections of pipework and other assets from rope or scaffolded access. This work is physically and mentally demanding. Inspectors tend to be cogitatively capable and personally individualist, requiring convincing of the benefits of any tool such as WWP before engaging. Two EPCM project engineers, working back to back who had previously participated in the implementation of the WWP in cycle 1, led the teams.

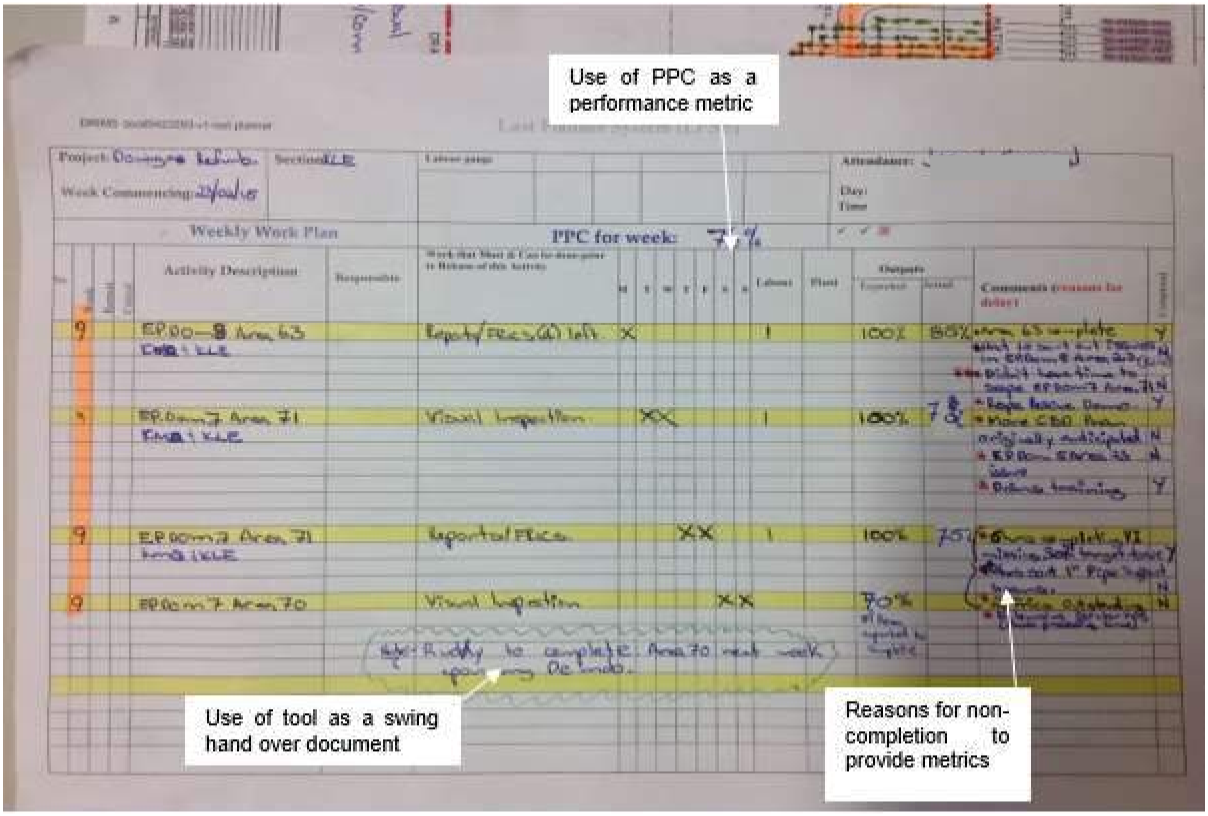


Figure 5:26- *(DOC 9: evolution of practice, team autonomy)*

The teams were not interrelated and therefore this implementation differed from previous cycles and from documented use. In this instance, each inspection team consisting of two to three inspectors working separately on their own scope. Yet, the implementation demonstrated some marked developments. After a period of three weeks of implementation, it was apparent that the inspectors were happy with the concepts and engaging with the use of the WWP. The PPCs were now trending at levels of between 70 and 80%, with the inspectors now populating the sheets with rich information on lessons learned and ideas for improvement. Furthermore, the WWP sheets were being used as an information handover document for incoming back-to-back teams (figure 5:26). The effective transfer of information and data between FIFO teams had been a largely non-resolved issue on the construction work scope during the time the researcher had spent at the plant. Yet, the inspectors on their own initiative used the WWP to go some way towards resolving the issue where the WWP was used as an information transfer mechanism for back-to-back FIFO teams. The implementation of the DH in this cycle is described below.

Daily Huddle (DH)

The inspectors and PEs developed the DH board to suit the work scope undertaken (figure 5:27).

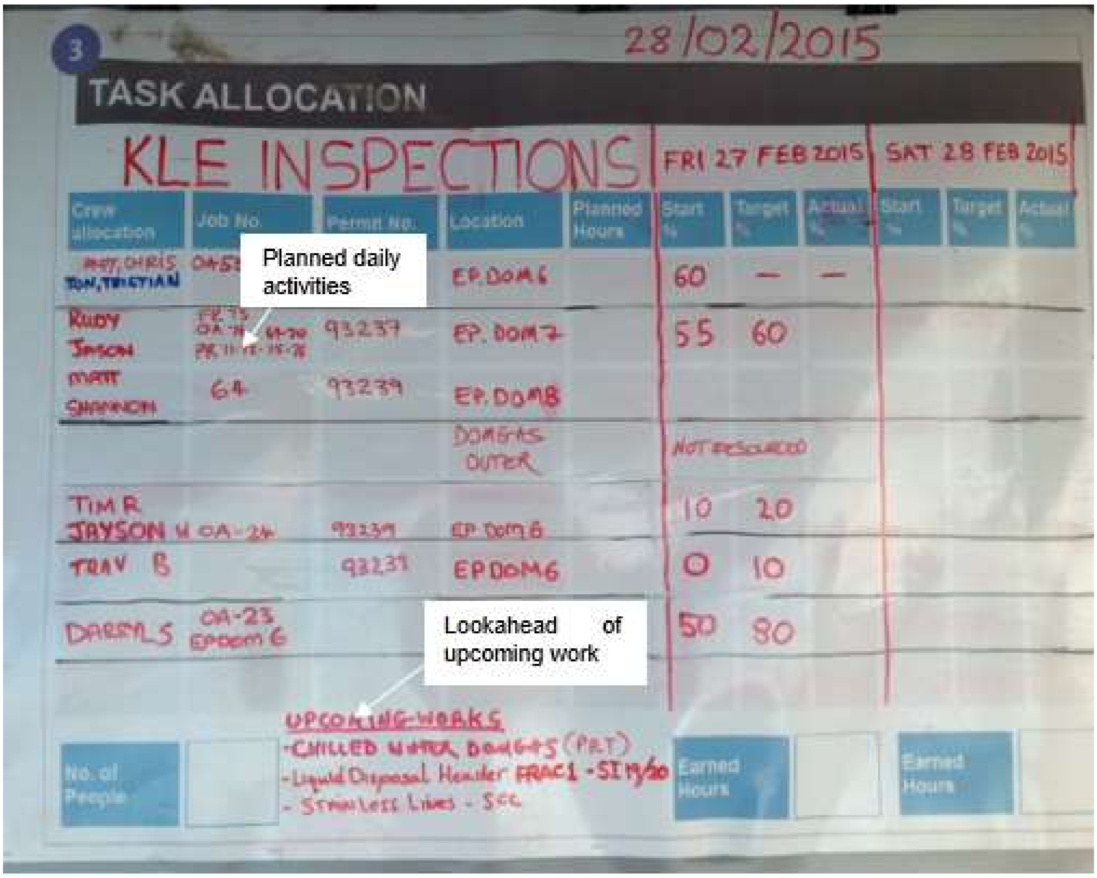


Figure 5:27-Inspectors DH board *(DOC 10: evolution of practice, team autonomy)*

This was a simplified version of the board used in cycle 5 where the inspectors stood in front of their peer group each morning and described the work they had completed on the previous day. They reported on, completion of committed forecasts, tasks they were expecting to do in the upcoming day and outputs expected.

5.6.2.3 Team Work Design (TWD)

The TWD was only fully developed in the last cycle to become a viable tool with development largely led by the workforce. Here the inspectors took part in a workshop to develop standard work design to be tested on site. This process evolved further where the PEs sent out questionnaires addressing eleven areas where innovative practice could be enhanced or developed. The replies were condensed into 13 “key takeaways” with 2 below (figure 5:28) which could be used to collaboratively develop standard work in a TWD process.

EPCM Key Takeaway: The integration of the Last Planner System has provided the implementation contractor with the opportunity to own the schedule. The sporadic and late delivery of work packs hindered the ability to correct plan and manage the scope. Changes in priorities affect productivity, having to mobilise personnel to different areas of the plant to meet imminent deadlines is best avoided through sufficient planning.
EPCM Key Takeaway: This example may be minor but when dealing with 1,000’s of previous defects, the order of magnitude impact matters. A best practice workshop to be held with the AICIP inspectors to capture lessons learned. The key output will be a modified FRIC and a series of recommendations to the client on managing previous defects and how the data will be managed for refurbishment.

Figure 5:28 – Inspectors questionnaire feedback *(DOC 14: evolution of practice, team autonomy)*

5.6.3 Summary

This cycle produced some of the most successful outcomes in the implementation process, built from the successes and set backs of the earlier cycles. There were several notable outcomes from this cycle, which included the demonstration of the workforces’ ability to evolve the tools to suit the environment and the work undertaken. This ability of the workforce to understand, evolve and adapt the tools in unexpected ways is an outcome not identified in literature. This process was demonstrated by the inspectors and PEs development of the DH board, used earlier to produce a board, distinct to anything in use on the plant (figure 5:27). This demonstrated team autonomy in the evolution of practice.

This cycle also had the first successful implementation of pull planning. There were several outcomes. Firstly, this is the first documented use of the tool that the researcher is aware of as a mechanism to develop a master programme. Secondly, the participants decided on a strategy to undertake the work before proceeding with the pull planning itself.

5.7 Cycle 7 Jetty Refurbishment

Figure 5:29- Cable pulling using winch

Figure 5:30 - Wagon assisted cable laying

EPCM #3 was the EPCM contractor with the IC contractor IC #1. This was the first time that the researcher had worked with this EPCM contractor. The LPS was used in this cycle where similar issues were experienced as in cycles 2 and 3 with inconsistent engagement experienced from the EPCM contractor, where some members of the management and supervisory team saw the merits and were keen to engage, and others less so. However, the implementation of the TWD in this cycle revealed unexpected outcomes. The project involved the refurbishments of jetty electrical and control system. Work include new instrumentation and cabling in an electrical sub-station and interconnecting power and instrumentation cabling over a 500m length to the jetties. Reflection of heat from the water and concrete surfaces resulted in air temperatures of up to 45ºC during the day at work fronts. The activity of pulling heavy cables along the LPG jetty was particularly arduous. The workforce including supervisory staff with some input from SC 16.

5.7.1.1 Team Work Design (TWD)

The last planners (LPs) involved in the WWP implemented in this cycle included superintendents and supervisors. These collaborated with leading hands (LH) and workforce members in the development of standard work using TWD. The researcher provided some guidance, but the development and testing of standard work in PDCA cycles was largely autonomous, collaboratively planned and implemented by the people doing the work. A TWD approach was employed when an initial method (figure 5:29), using a winch to pull cables on the jetty refurbishment proved slow and cumbersome. The workshop (figure 5:31) was used by the workforce to develop a prototype (figure 5:30) using a wagon with a cable spool mounted on a frame. This method, was improved in PDCA cycles by the workforce. The process and outcomes, described as follows in a paper by the researcher demonstrate the process of building higher performing teams:

- *The leading hands (LHs) create the philosophy and develop the work design.*
- *The workforce knows the job because they own it and built it.*
- *People sometimes struggle with complex drawings but understand the job from discussions and the visuals.*
- *The process gives a common sense of ownership to those involved.*
- *Relationships are strengthened as team members are tutored, coached and mentored in the walkthrough and team members build broader relationships with each other.*
- *Crew members understand each other's individual strengths and weaknesses because of the rich conversations that occur.*

- *Problems that are difficult to resolve are left by team consent with the commitment to come back later with a fresh perspective.*
- *The process delegates the work to the LH's and confirms the LH's understanding of both the scope and hazards.*
- *People discuss the productivity rates they will expect and take ownership of both process and what success looks like, (Hackett et al., 2015).*

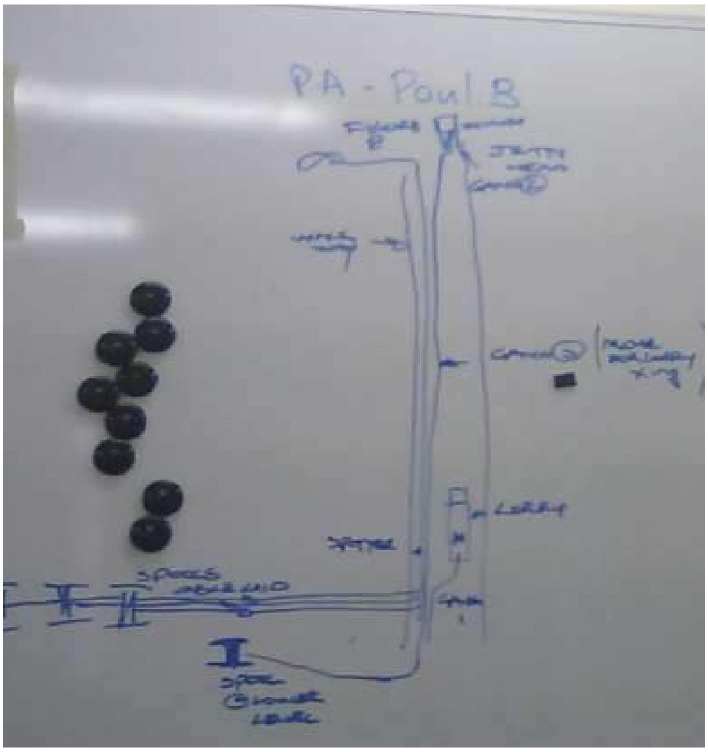


Figure 5:31- Developing the prototype

All the above demonstrated the potential of the tool once it was finally accepted, but also workforce ability to own and control its implementation in a collaborative manner, in the process building a higher performing team from the existing. This was the first time that the TWD fully utilised the PDCA cycle where a prototype developed in a work shop was used as standard work in a FRS trial.

5.8 Action Research Findings

The early AR cycles revealed the importance of obtaining support from management and supervisory staff, with this support more likely from those with existing lean or lean type experience. Once identified, people with this experience acted as supporters and catalysts of change, providing support and displaying leadership whilst assisting in the implementation. One finding was the impact informal leaders had on implementation, with these informal leaders identifiable at forums such as the H&S prestarts. The AR demonstrated the difficulties encountered in the implementation process including a demonstration of the low value placed by some management on the concept of crew centric planning. This attitude was also displayed by some supervisory staff. However, somewhat at odds with literature, these "resistors" were not ultimately disruptive but proved to be some of the strongest advocates. The culture was identified as clan orientated with loyalty and collaborative teamwork valued, (Oney-Yazici et al., 2006, Arditi et al., 2017), and success measured in terms of fulfilling customers' requirements (Cameron and Quinn 2011).

Whilst it is widely accepted that lean tools such as the LPS facilitate learning (Kalsaas 2012, Alves et al., 2012) there is little lean literature describing operationalisation, apart from some description of the use of First Run Studies (FRS) (Ballard and Howell 1997) using existing knowledge in the development of learning and continuous improvement. Furthermore, Pasquire describes the 8^{th} Flow; common understanding as a means of transferring knowledge, but does not describe operationalisation of the process. Also, Chinowsky et al., (2008) notes that high performing teams in construction projects can problem solve with an ability to exchange project information, knowledge, insight, thereby enhancing the group's capabilities, but notes that there is little interest in implementation. To close these gaps the researcher developed and implemented a tool called Team Work Design (TWD) facilitating the 8^{th} flow, enabling the development of higher performing teams from existing ones. The implementation and outcomes are tracked in the AR cycles from good engagement from the last planners in cycle 1 where some standard work prototypes were identified, but could not be tested further, due to the subsequent breakup of the group. Poor outcomes were experienced in cycle 3, where a lack of discipline in organising the workshop involving participants with no prior interface with the lean construction implementation. This was followed by improved engagement from the workforce, supervision and project engineers (cycles 5,6) to the final implementation with the first use of a PDCA cycle, demonstrating the development of a higher performing team, autonomously developed a prototype to improve cable pulling in a work shop, tested in a first run study (FRS) to develop standard work.

An outcome not identified in literature was the demonstration of workforce ability to lead the development and evolution of the tools to suit their environment, a factor demonstrated in cycles 4, 5 and 6. The workforce revealed an ability to autonomously develop standard work, by identifying and reducing waiting time (figure 5:17), using the WWP sheet as a handover over document between FIFO teams (Figure 5:25) and autonomously developed standard work (cycle 7).

In addition, whilst lean literature (Kalsaas 2012, Alves et al., 2012) discusses the use of the lean tools as an aid to learning, there is a shortfall in the literature discussing the learning process itself. Research by Kalsaas (2012) suggests that lean construction forums can become a “safe place" for learning. Yet, there is little evident research into these forums facilitating learning during the implementation of lean construction. The cycles illustrated how the TWD incorporated into the LPS, facilitating learning and continuous improvement, with forums such as the Weekly Work Plan (WWP) enabled the quieter reflective personalities to plan and organise their upcoming work by stepping back and evaluating constraints and commitments. Some of the WWP meetings and workshops with the best outcomes had a mix of personality types where informal leaders demonstrated their abilities to engage participants. There were also early indications that the workforce was not averse to change and that language usage is an indicator, demonstrated positive engagement with change.

The literature demonstrates difficulties encountered whilst implementing lean tools. The AR addressed a gap in literature that whilst there are many papers that discuss barriers and potential approaches to address these barriers, there is little indication of practitioner literature investigating longitudinal lean construction implementation to determine implementation guidance. Therefore, research findings were used to develop lean implementation guidance (table 6:1).

The AR also charted the continuous improvement of the DH with several outcomes not identified in literature. Firstly, cycle 2 demonstrated the use of the DH to set the time work started at job fronts, with evidence in cycles 2,3,4 that even short delays in the DH huddle start has a disproportionate effect on work starting. Furthermore, the workforce demonstrated the ability to evolve the use of the DH, moving it to a quite zone (figure 5:3), it’s use by H&S and QA/QC staff to get relevant messages out to the workforce and management (table 5:4) and its evolution to encompass the H&S briefing, using a board as a focal point (section 5.5.2.1).

6 Research Findings and Contributions

This chapter draws the research findings together, which includes findings on the applicability of the lean construction approach to mitigate against EC performance issues, particularly those pertaining to refurbishment works the particular culture, issues around the use of Critical Path Method (CPM) scheduling, guidance for implementing the Last Planner System (LPS) on future projects and information on the use of Team Work Design (TWD).

6.1 Lean Construction in EC

The aim of the research was to determine the impact of a collaborative approach to planning on performance outcomes in EC projects and develop guidance for implementation. The research proposed the use of lean construction to address refurbishment issues in particular and EC in general. There was evidence of some previous lean construction implementation, interestingly by the SC itself, used in the completion stages of Pluto LNG plant construction, situated adjacent to the KGP (Morgan and Coci 2012). Yet, there was no evidence of implementation being sustained. Nguyen (2013) describes lean construction workshops delivered to Australian EC clients, with no further discussion on application. It was apparent that lean construction is an immature approach in the Australian EC industry. Therefore, existing documentation was quantitatively analysed to provide information on issues impacting on performance and determine if lean construction could be an appropriate antidote. Potential wastes uncovered included transportation and movement with further evidence of poor planning outcomes during project execution. Waste reduction is the most important element of lean construction (Green 1999, Ballard and Howell 2003, Jorgensen and Emmitt 2008, Mao and Zhang 2008, Eriksson 2010), with efficient storage and transportation of parts and materials, crucial to waste reduction (Eriksson 2010, Fearne and Fowler 2006). Furthermore, the LPS is a collaborative planning tool. Therefore, a gap in literature was addressed, with evidence produced for the suitability of lean construction to address EC performance issues.

6.2 Culture and Environment

A further gap in literature addressed was the lack of research into Australian EC workforce culture. Research revealed a predominantly clan workforce culture where loyalty is valued in teams participating together with success determined by providing value to the customer (Oney-Yazici, Arditi and Uwakweh 2006, Arditi, Nayak and Damci 2017), be that the end user or those at work handoffs. Success is measured in terms of fulfilling customers' requirements (Cameron and Quinn 2011).

The workforce engaged with onerous H&S issues proving adept in the use of the complex Integrated Safe System of Work (ISSOW). Informal leaders, normally supervisors, identified in the Health & Safety (H&S) daily prestart meetings proved pivotal in the implementation process, being most likely to be the early adopters of the lean tools and then lead the process. A further finding was workforce ability to understand lean concepts such as waste, autonomously developing strategies to mitigate against potential waste identified. Furthermore, an ability was exhibited to independently evolve the lean tools in response to requirements.

Finally, a relationship was established between performance and organisational culture. Performance can be measured in terms of schedule, quality, environmental impact, work environment and innovation outcomes (Eriksson and Westerberg 2011). As noted the culture was established as a clan culture, where loyalty and collaborative teamwork are valued, with success determined by providing value to the customer (Oney-Yazici et al., 2006, Arditi et al., 2017). Higher performing projects have higher team orientation, where effort is expended on enhanced workforce motivation, teamwork, open communication across projects including information to the workforce, site tidiness, positive affirmation of good performance, participation in learning, decision making and planning and good management/workforce communication (Ankrah 2007). The workforce participated in learning, autonomously developing process and standard work, thereby developing higher performing teams producing higher performing projects. Performance enhancement were measured by innovative practice development and improvements in schedule time. Two cycles, cycle 1 and 5 showed a reduction of scheduled time. Development of innovative practice has been described. The research demonstrates the clan culture facilitating performance improvements whilst using a lean construction approach in project execution.

6.3 Critical Path Method (CPM) usage

The research closed a gap in literature regarding use of the Critical Path Method (CPM). The literature revealed issues with CPM in developing project master schedules. Despite its widespread use globally in the construction industry it is still not fully accepted or consistently used (Galloway 2006). CPM is ineffective in dealing with multiple constraints such as deadline and resource limits (Hegazy and

Menesi 2010), does not allow for the interruption of activities (Shi and Deng 2000), and whilst useful for reporting, is less useful in reflecting the project reality in order to support decision making (Hegazy and Menesi 2010). Furthermore, some research demonstrates misuse of the software to produce illogical impractical schedules (Korman and Daniels 2003). However, there is little evidence of research into its use on EC projects. Analysis of 21 semi-structured interviews revealed several issues with its use as a scheduling mechanism on the projects investigated. These included inexperienced planners who struggle with the complexity of CPM scheduling, compounded by poor or inaccurate data, endeavouring to produce schedules made to "work" by delinking activities. Furthermore, supervisory staff found scheduling outputs difficult to understand, raising questions over the usefulness of these outputs, even if accurate.

6.4 Team Work Design (TWD)

A tool called Team Work Design (TWD) was developed and implemented by the researcher assisted by the literature and in response to gaps. Whilst several authors recognise that the LPS facilitate learning (Kalsaas 2012, Alves et al., 2012) with some description of the use of tools such as First Run Studies (FRS) (Ballard and Howell 1997) aiding the process there is little evidence of operationalisation. Furthermore Seddon (2003) that those tasked with undertaking work tasks are in the best position to design those tasks. In response, the researcher designed and implemented a tool coined Team Work Design (TWD), simply called this as the teams executing work activities iteratively designed continuously improved standard work using Plan, Do, Check, Act (PDCA) cycles. TWD was realised with variable outcomes several cycles.

The first TWD workshop was undertaken in this cycle with engagement displayed by participants, but no opportunity to test prototypes in further first run studies (FRS). TWD was executed next in cycle 3, exhibiting poor outcomes, due to participants with no prior experience of the lean tools and to a poorly defined scope in the work-shop implementation. Better engagement was witnessed in cycle 4 where inspectors used a white board to develop some standard work prototypes, but with little opportunity to test these in First Run Studies (FRS). Cycle 7 revealed the workforce ability and tenacity to collaboratively conceptualise and test a prototype to develop standard work whilst building a higher performing team from an existing one. This was one of the first times that the TWD fully utilised the PDCA cycle where a prototype developed in a work shop was used as standard work on site.

6.5 LPS Implementation and Guidance

AR was undertaken in 7 cycles investigating the implementation of Team Work Design (TWD) integrated with the Last Planner System (LPS), with the outcomes of each cycle informing the implementation of the subsequent cycle. The LPS, was originally developed as a workforce led production-planning tool by Glen Ballard and Greg Howell, following research demonstrating poor prediction of production outcomes achieved by site supervision (Ballard 1993, Koskela and Ruben 2001). TWD, which supports teams in the design and implementation of standard work was developed by the researcher and implemented alongside the LPS over the course of the research.

The first cycle involved the shutdown targeted inspection campaign (STIPS) with data analysed using visual and qualitative approaches. Embedment of the LPS proved initially problematic but demonstrated improvements, assisted by leadership exhibited by management with pre-existing lean type knowledge. A positive correlation was exhibited between high PPCs and performance levels achieved, where high PPCs levels correlated positively with time performance. A similar outcome was not obtained until later cycles.

The second cycle was undertaken on an outage of the Domgas 1 train, which supplies LNG to the domestic market, with difficulties encountered in reintroducing the tools in a new cycle. Implementation revealed overt workforce resistance, but also tacit management resistance to the concept of collaborative production planning led by decision makers. The DH was now used to set the working day start time, with evolution displayed, where site management, including SC personnel deferring to the huddle leader when attending the DH. The health and safety (H&S) and the quality control (QA/QC) advisors used the DH as a forum to convey key data or information. DH commencement timeliness was a predictor of shift workflow and synchronisation, with even a 5-minute delay resulting in disproportionate delays in work commencement. The need for implementation clarity and consistency resulted in the development of a guidance sheet (DOC 4). The learning outcomes used in the implementation of cycle 3 were the need for discipline and clarity in the implementation and the ability shown by the workforce to evolve usage.

The third cycle was undertaken in an outage of the Domgas 2 train, supplying gas to the domestic market along with Domgas 1 train. Ongoing implementation challenges were experienced. Variable outcomes were witnessed, with evidence that DH usage would not automatically transfer from project to project, even with the same staff and workforce. Also, variable discipline in terms of WWP meeting attendance and preparation was experienced. This resistance to the notion of formal planning was referred to by SC 01 as “being too busy cutting wood to sharpen the axe”. Cycle 3 demonstrated the ongoing challenges in establishing stability in the implementation of the Weekly Work Plan (WWP). One reason was the lack of scheduling knowledge that many of the supervisory staff displayed. In addition, the introduction of two or more inexperienced last planners (LPs) destabilised the process. Yet, there was more evidence of evolution of practice in DH use. This was initiated by one of the superintendents and involved the introduction of a discussion on the key H&S issues for the day. The timing of the DH was again an indicator of how the working day would unfold. Once again, the EPCM management and informal leaders were the people who provided the leadership and commitment in this process. In addition, night shifts, with fewer managers present had a less stressed atmosphere than days. CPM project milestones are used to inform production planning but issues with the complexity and accuracy of the CPM schedules impeded WWP production. This cycle again demonstrated the ability of the workforce to evolve and shape the tools to suit their needs, with evidence of informal leaders assisting harmonious work practice.

Cycle 4 was implemented on the LNG 1 pre-shutdown scope of works. Again, the DH set the workforce arrival time to the work fronts, with actual arrival times an indicator of how quickly and efficiently work groups would start work. In this cycle implementation stabilised faster than in earlier cycles, assisted by the support of EPCM site management. The cycle showed practice instigated by LPs who insisted on gaining commitments from their leading hands before they could make commitments themselves, so involving their own supervisory staff in commitment making. In addition, this cycle demonstrated a high level of workforce synchronisation. This was demonstrated initially in the DH where it quickly became established to give synchronised workflow. Furthermore, the embedment of the WWP was accompanied by a change in language where the LPs used the word “commitment” to describe promises made during the weekly WWP. This cycle was also used to introduce pull planning (PP). These was some interest and engagement, but this was proving the most difficult tool to introduce and embed.

Cycle 5 investigated the use of the LPS, on metering refurbishment of a section of the plant that delivers natural gas to Western Australia. Pull planning was reintroduced in this cycle with supervisory staff and workforce demonstrated team autonomy and evolution of practice by developing a variant of pull planning, aiding the collaborative development of achievable master programme milestones. In this cycle, a disciplined approach was established with the DH starting at a set time, using the pre-start boards as boundary objects with the WWP and PPC trends displayed. This demonstrated an evolution of practice where an existing initiative using a prestart board was incorporated into the DH, which now combining H&S, schedule and quality. The DH now integrated the previous separate H&S pre-start meeting. A correlation was exhibited between PPC metrics and improvements in performance, measured in project time reduction. These improvements were in the order of 25% once PPCs consistently trended at 70-80% levels.

Cycle 6 produced some of the most successful outcomes in the embedment of the tools, built on the successes and set backs of the earlier cycles. There were several notable outcomes from this cycle, which included the demonstration of the workforces' ability to evolve the tools to suit the environment and the work undertaken. This process was demonstrated by the inspectors and project engineers (PEs) development of the DH board, to produce a board, distinct from anything in use on the plant. This demonstrated autonomous evolution of practice. This cycle also had the first successful implementation of pull planning. There were several outcomes. Firstly, this is the first documented use of the tool that the researcher is aware of as a mechanism to develop a master programme. Secondly, the participants decided on strategy for undertaking the work, before proceeding with the pull planning itself.

Attribute	Literature	Research	Findings
Use of performance indicators to track implementation impact	Literature demonstrates difficulties encountered when using productivity metrics to track the impact of performance enhancing initiatives. Measuring performance in terms of time, cost, quality and innovation embedment proves a simpler approach.	Performance variance was measured in terms of time and embedment of innovative practice.	**Recommendations:** Agreed performance indicators with senior management prior to undertaking improvement initiatives.
Use of CPM milestones in production planning	Ballard et al. 2016 stresses the importance of using CPM for project planning, informing the LPS production planning.	Issues encountered across the cycles in obtaining meaningful milestones from the CPM/EVM schedules. Section 4.1.4 investigated the use and issues with the CPM/EVM schedule outputs	**Recommendations:** Engage with the planners at an early stage to agree mechanisms to develop robust milestones.
Disciplined approach	There is a shortfall of evidence of literature investigating the use of a disciplined approach in the implementation of lean construction.	There was evidence in the research process of the impact of discipline or lack thereof whilst implementing lean construction tools. **Weekly Work Plan (WWP)** The Thesis demonstrates the difficulty encountered in the implementation of a set time agreed by common consent for the WWP meetings. **The Daily Huddle (DH)** **1.** The research demonstrated that the DH timing can be used to set the timing for workforce arrival at work fronts. **2.** Late arrival by workforce members to the DH had a disproportionate effect on commencement of work and the subsequent workflow. **Standard implementation approach** Misunderstandings exhibited by workforce caused by early lack of a standard implementation approach.	**Recommendations** **1.** Agree timings by common consent of meetings such as the WWP. Strongly encourage timely attendance with Last Planners (LPs) fully prepared. **2.** Agree timings of DH with input from management. **3.** Use examples where possible from implementation of the lean tools from the existing environment. **4.** Develop a standard implementation approach.
Strategy development	Little lean literature on the collaborative development of a work strategy providing guidance on work scope implementation.	Decision makers involved in the phase planning in cycle 6 collaboratively developed a strategy as to how workscope would be undertaken. Development of “templates” used in the development of CPM schedules during pull planning workshops.	**Recommendations** Develop a strategy or a philosophy as to how the work should be undertaken at early planning stage.

Introduction of new Last Planners (LPs) to the WWP meetings	Little literature on how one should address potential pitfalls in the implementation of new and inexperienced LPs to the WWP meetings.	Introduction of two or more new LPs with no prior knowledge of the WWP had a destabilising effect on the meeting (WWP 9,10). However, more positive outcomes were observed following further meetings (WWP 11).	**Recommendations** Care to be taken when adding new LPs to the WWP meetings. Provide coaching and mentoring in advance.
Informal leaders	Ross Hills (2014) notes that informal leaders may not have formal authority to direct a group but will stand up and act, that informal leadership is the ability to influence the behaviour of teammates through means other than formal authority. Informal leaders can influence to achieve at higher levels than normal. Pescosolido (2001) says that informal leaders in a group play a key role in developing group efficacy. Zhang et al., (2012) note a shared team vision encourages the emergence of informal leaders.	The research demonstrated the impact informal leaders had on the implementation of the lean tools. Those identified at the early health and safety prestart meetings were supervisors including IC 01 and IC 02.	**Forums** Informal leaders identified at forums such as H&S pre-start meetings **Profile:** Informal leaders tended to be supervisors employed by implementation contractors (IC). **Engagement** The researcher spent time discussing and descripting lean construction concepts. **Outcomes** Informal leaders lead t implementation, mentoring others in the process.
Team size	Literature demonstrated that team size impacts on the information and knowledge transfer where teams with than 9 members become less efficient (Hoegl 2005, Cummings 1978).	Team sizes were maintained at 9 or less where possible when implementing tools such as the WWP meetings and the Pull Planning workshops. It proved more difficult to keep the attendance at the DH below 9 people, due to the interest of supervisory staff and support staff in attending.	**Recommendations** Maintain teams at 9 or less members where possible.
Implementation resistance	Literature reveals an intolerance of people resistant to change (Kotter 1996). Naysayers or resistors are described as those who resist change and are particularly disruptive when organisations initiate change. They see change as disrupting the status-quo, affecting their perks (Luecke 2003, p.75).	The research demonstrated that the view of resistors as disrupters was not universally true. An early resistor (CON 2) proved to be one of the more powerful advocates, once his concerns were acknowledged and respected. More subtle resistance from management (CON 3) appeared to recede as the research implementation progressed.	**Sources of resistance** 1. Tacit resistance from managers. "workers should be working not planning" 2. Explicit resistance from supervisors **Recommendations** Acknowledge concerns, engage with resistors to understand and address concerns. Learn from concerns.

Commitment making	Literature references the gaining of commitments from the LPs involved in the production planning process (Ballard and Tommelein 2016, Ballard 2000). However, there is little evidence of discussion on the nature of the commitment making process.	The scaffolding supervisor IC 05 demonstrated a keen understanding of the concept of making commitments and who should make them in the LPS (WWP 12). He remarked that he needed to get commitments from his own leading hands before he could commit to next week's production planning.	**Recommendations** Commitments can only be made by people who can carry out actions committed to. Getting commitments from decision makers such as leading hands in advance locks them into the decision making/commitment process.
Pre-existing lean or lean type knowledge	There is a paucity of literature in lean construction on the engagement of people with previous lean type knowledge.	**People with knowledge** 1. SC 15 who had previously been involved in a lean initiative earlier in his career understood the concepts, provided strong support (MEET 3). 2. Implementation Contractor (IC) managers with previous knowledge proved to be strong advocates and leaders of the implementation (Cycle 2, 3,4).	**Profile** People with existing knowledge included SC superintendents and EPCM managers. **Identification** Through continuous conversations and discussions with management and supervisory staff **Outcomes** People identified were the most supportive in the implementation process, leading and mentoring implementation. **Recommendations** The first and most important implementation phases is the identification and engagement of people with existing lean or lean type knowledge.
Existing initiatives	There is little literature investigating the incorporation of existing initiatives to assist in lean construction implementation.	The Daily Huddle (DH) implementation used an existing visual board (figure 5:19) developed by the KGP SC continuous improvement team and subsequently used by the consultant in the productivity improvement initiative.	The DH pre-star board (figure 5:20) acted as a focal point for the morning pre-starts. A similar board was already in use at the KGP shutdowns, providing a link to existing practice and the lean construction implementation. **Outcomes** The implementation gained acceptance more quickly in this cycle aided in part by familiarity with the board. Variants developed by the inspectors (figure 5:27) were also used where acceptance of the LPS was swifter than in previous cycles. **Recommendations** Seek out and apply existing lean type initiatives/practices wherever they are evident. Apply these where possible and help the owners understand that they are already using a lean approach

Language as an indicator of engagement	There is a paucity of lean literature on language as an indicator of workforce engagement with the implementation process.	The Last Planners used the term commitment in describing their own and others role in the implementation process of the Weekly Work Plan (WWP). • IC 01asking the assembled last planners (LP) whether they could commit to activities (WWP 7). • IC 05 the scaffolding supervisor used the term when explaining when he had to obtain commitments from his own leading hands before making commitments himself at the WWP meetings (WWP 12).	**Findings** The use and understanding of terms such as "commitment" occurred at points in the implementation where good LP engagement was observed. **Recommendations:** The use of language should be observed during the implementation process. Furthermore, the meaning and relevance of terms such as commitment should be made clear.
Training in the art of planning	The literature reveals some shortfalls in the implementation, use and understanding of the CPM by planners, supervision and the workforce (Korman and Daniels 2003, Shi and Deng 2000, Hegazy and Menesi 2010).	The primary research revealed issues with some planner's levels of expertise and relevant experience with further evidence of a lack of understanding of the scheduling process and reporting out puts by supervisory staff (Section 4:1:4).	**Recommendations** Provide suitable training for front line supervision and planners in the "art of planning".
Use of boundary objects	Boundary objects are artefacts or narratives assisting the transfer of knowledge and information among teams (Carlile 2004, Levina 2005).	The research revealed existing use of narratives particularly in the H&S prestart meetings (HSP2, HSP3). Boundary objects such as the paper WWP sheets, post-its and white board were used during the research, with a particularly boundary object, the DH visual board (Figure 5:20).	**Recommendations** Give priority to using boundary objects, particularly narratives to facilitate tacit knowledge transfer (Bartel and Garud 2003).
Evolution of tools	There is little direction in lean literature on how lean tools can be evolved and adapted for particular environments.	The Daily Huddle (DH), a component of the LPS demonstrated visible evolution over the course of the primary research, in many cases led and instigated by the workforce itself. These included: • Undertaking the DH in a "quiet zone." • One person usually a superintendent or manager leading the DH. • Use of DH by Health & safety advisors and QA staff to directly communicate relevant information. • Use of the DH to set the time work commenced at shift start. Evolution of the forum incorporation a visual board acting as the focal point, where information on production activities, quality and health & safety issues were communicated and discussed.	**Recommendations:** Be prepared for and encourage evolution of the lean tools as dictated by the work environment and led by a workforce with appropriate experience and knowledge.

Use of Pull planning to develop the Critical Path Method (CPM) schedule.	The lean literature refers to the use of the CPM to provide project planning milestones used to provide the target dates in LPS production planning (Ballard and Tommelein 2016). However, there are little reference to the use of the LPS aid development of the CPM schedule.	Cycle 6 illustrated pull planning used in the development of CPM master schedules.	**Recommendations** Gather decision makers including project engineers, managers, superintendents and supervisors and include planners so they understand the work flow in pull planning workshops to collaboratively agree "templates" to be used develop the CPM schedules. The decision makers then have early involvement in schedule development.
Enable Autonomous workforce evolution of lean practice	Commentators such as Kalsaas (2012) notes that LPS forums of practice provide a safe place for participants to share knowledge and learn. However, there is little literature on the autonomous workforce development of the tools to develop standard practice.	Autonomous evolution of practice observed in the following **1. Development of a means to counter variability and waiting waste** The nature of Fly in Fly out (FIFO) working at the plant gave rise to workforce variability. This resulted in "waiting" waste caused by uncertainty on gang members and available work with workers milled around at the work-fronts as shifts started. Scaffolding supervisors also acting in LP roles autonomously developed a solution involving a visual aid (Figure 5:17) that tracked and allocated available resources, to appropriate work fronts. **2. Information gathering for standard work design implementation** Inspector project engineers canvassed inspectors using questionnaire to gather information on work scope that lent itself for improvement in Team Work Design (TWD). **3. Workscope execution strategy** Teams including supervisory staff, managers, project engineers and planners developed the concept of the development of a guiding strategy before undertaking a particular work scope. Strategies so developed included undertaking work on a pipe rack from top down rather than bottom up (Cycle 6). **4. Iterative autonomous development of standard work** Autonomous implementation of a standard work design by the workforce to develop improved work flow in a cable laying operation.	**Recommendations** Fully engage the workforce in the lean implementation process whilst respecting their knowledge and experience.

Table 6:1 Implementation Guidance

6.6 Achievement of the Research Objectives

Chapter 1 introduced the thesis and presented the rationale for the research, which informed the research aim and objectives. It also described the location and the challenges of refurbishing a live LNG plant. Chapter 2 undertook a literature review of the domains of knowledge pertinent to the thesis. Chapter 3 described the research design and methodology development. Chapter 4 describes the early exploratory research, the longitudinal observational research, the semi-structured interviews used to investigate the use of the Critical Path Method (CPM) of project. Section 5 describes the Action Research (AR) undertaken over 7 cycles. This chapter describes the conclusions. The results of this research were analysed to address the 4 objectives. These were set in pursuance of the research aim, which was, to determine the impact of a collaborative approach to planning on performance in engineering construction and to develop guidance for implementation. The outcomes are described below.

6.6.1 Objective 1

The first objective was *to investigate the implementation of the Critical Path Method (CPM) of project planning in EC projects.* The research used several methods to clarify the effects of the CPM in planning projects. Qualitative data from semi-structured interviews with quantitative primary and secondary data was analysed to investigate the effectiveness of CPM planning. Quantitative analysis revealed misalignment between CPM reporting and "reality". Qualitative analysis of the semi-structured interviews established shortfalls in planner expertise, but even those with expertise were hampered by incorrect and poor data, with evidence that schedules were being "made to work" by delinking activities. Furthermore, supervisory staff found CPM schedules impenetrable and difficult to understand. They were also tasked with collecting data to inform the scheduling process, with minimal training provided and the collection process viewed as waste. Some proposals were put forward to improve the effectiveness of CPM use. These included the development of a structured training programme for supervisors on the basic principles of planning and the development of a structured career path for planners to included onsite experience. Yet, some issues revealed by the research were acknowledged by the researcher as being more intractable including the complexity of the software and data input requirements.

6.6.2 Objective 2

The second objective was *to reveal the culture and environment of an EC workforce to understand its' impact on performance.* A literature search investigated available information on EC workforce capabilities and attributes. Observational research (chapter 4) was undertaken over an 18-month period to investigate EC workforce culture and work environment, in this case the refurbishment of an LNG facility. The culture was identified as a clan culture, described as a culture where loyalty and collaborative teamwork are valued, with success determined by providing value to the customer(Oney-Yazici, Arditi and Uwakweh 2006, Arditi, Nayak and Damci 2017). There is an expectation that the workforce has spatial and situational awareness, good retentive memories and superior communication skills, especially at supervisor level. These skills are highly valued. The workforce work in a high-risk environment. The risk includes H&S and process risk. The workforce engages readily with onerous H&S requirements, are astute and capable, demonstrating an ability to evolve the lean tools in response to the environment and to independently lead lean construction implementation. This demonstrated the value placed on the learning process. These was also evidence of a culture that valued the ability to work in a tough environment. There is a willingness to question authority, an attribute particularly demonstrated in the H&S prestart meetings. There was also evidence of informal leaders among the workforce, who as well as leading the implementation of the lean tools, mentored and supported other members of the workforce.

6.6.3 Objective 3

The third objective was *to reveal the current factors that affect performance in EC projects and to verify the implementation of a collaborative planning approach in EC*. The early exploratory research analysed the SC secondary data to reveal information on factors influencing the performance levels achieved. There was no evidence of previous analysis. Analysis revealed that the main factor affecting performance after tornados was transportation and movement potential waste and planning at project implementation level. This demonstrated the suitability of the LPS, a collaborative production-planning tool used to reduce waste. The early AR cycle investigated the impact of Team Work Design (TWD) integrated into the LPS on performance. Improvement in schedule time was achieved, demonstrated the efficacy of lean construction to act as an antidote to the potential waste and planning issues observed. Furthermore, performance enhancement was demonstrated by development and use of innovative practice. This cycle revealed the workforce engaging with the use the LPS with TWD, with resultant performance improvements.

6.6.4 Objective 4

The forth objective was *to develop LPS implementation guidance, including any necessary supporting approaches.* The guidance is presented in table 6:1. A tool called Team Work Design (TWD) was developed by the researcher and implemented by the workforce over the course of the longitudinal primary research and integrated into the LPS. TWD was implemented for two reasons. Firstly, to address a gap in knowledge, which was the operationalising of the 8th flow, common understanding. Secondly, the tool facilitates the development of higher performing teams from existing ones. The study provides a description the implementation (section 5.7.1.1) to assist execution on further projects.

6.7 Contributions to Knowledge

The study contributed to knowledge, firstly by the investigation and demonstration of the abilities and culture of the Australian EC workforce. The literature (Chapter 2) highlighted conflicting views on the abilities of the Australian oil and gas workforce. Whilst commentators stated that the workforce was less productive than the best seen globally (Ellis and Legrand 2013), more thorough researchers disagree. These note, that the Australia work force match the best globally (Merrow 2011) and state that poor performance experienced, stems from a shortfall of management experienced in undertaking large scale EC projects. The observational research revealed an able work force contending with the physical demands of the work scope and the environment with a culture identified as a clan culture. Clan cultures value, loyalty and team work, to provide customer value. They had an ability to meet cognitive demands caused by the need to understand intricate work scope and complex process. They also effectively manage the ever-present spectre of risk including H&S risk and process risk. A second contribution to knowledge was the demonstration that pre-existing lean or lean type experience proves pivotal in early embedment of lean tools with many of these people proving particularly strong advocates during the embedment process. The research revealed the influence and importance of informal leaders, initially identified at the pre-start H&S meetings. These people once identified and engaged led the implementation, using language including words such as “commitment”, an indicator of engagement and interest. Thirdly, the research revealed the workforce’s ability to instinctively understand at a fundamental level, concepts such as waste and then independently develop approaches to address waste such as waiting. Furthermore, the workforce had capability to independently evolve the use of the TWD tool, in the process developing standard work design. The study also contributed to knowledge by the demonstration of the disproportionate effects of short delays in commencing the Daily Huddle (DH) had on subsequent commencement times as work fronts.

The study contributed further to knowledge by building on existing literature on the implementation and usage of the CPM. The literature in Chapter 2 revealed shortcomings with the use of CPM/EVM. There is a lack of expertise and knowledge in the industry regarding its use, with the workforce finding the tool difficult to use (Galloway 2006). It can be ineffective when dealing with multiple constraints such as deadline and resource limits (Hegazy and Menesi 2010), does not allow for the interruption of activities (Shi and Deng 2000), and there is some research showing the software used to produce illogical impractical schedules (Korman and Daniels 2003). The research built on this knowledge, using a mixed methods approach with qualitative thematic analysis of semi-structured interviews and quantitative data analysis using graphs. Whilst literature demonstrated some issues, the research revealed deeper fundamental shortcomings with CPM/EVM, including misalignment of reporting and actual progress on the work fronts. There was evidence of a lack of appropriate planner experience and training, with software complexity presenting barriers to good planning outcomes. This complexity contributed to scheduling that lacked logic and flow. The planners used several strategies to overcome complexity including delinking activities. There was also a lack of understanding of planning outputs displayed by many of the supervisory staff, in part due to their career paths and a lack of appropriate training. Thus, the CPM outputs used to inform the LPS, proved ineffectual in providing reliable information in the weekly production planning. The contributions are summarised as follows.

- The study has revealed workforce culture and abilities in a particular EC environment.
- The demonstration of the extent of pre-existing knowledge of lean or lean type knowledge in the workforce and how this knowledge aids implementation of LPS incorporating TWD.
- The study has demonstrated the extent of existing workforce understanding of waste and their ability to develop mechanisms to counter this waste.

- The study has demonstrated the effect informal leaders have on lean construction implementation and forums where these people can be identified.

- The study has provided evidence of the disproportional effect short delays in the commencement of lean tools such as the DH have on subsequent workflow.

- The study had demonstrated issues regarding the use of CPM/EVM scheduling.

6.8 Contributions to Practice

The study provides guidance for the implementation of the LPS (table 6:1table 6:1), Furthermore, the Team Work Design (TWD) tool was developed to address a gap in academic and practitioner practice, identified in the literature review. Little guidance is given on methods to assist knowledge transfer among and between teams in construction projects and so operationalise the concept of the eight flow, common understanding (Pasquire and Court 2013).The tool was employed to aid knowledge transfer in existing teams, creating higher performing teams from existing ones with its implementation described. Furthermore, the implementation of the pull planning workshops demonstrated an alternate approach than commonly practiced, with pull planning used to inform the development of the CPM schedules. Additionally, templates and work strategies were developed in the pull planning workshops, with the planners and project engineers (PEs), using these to inform the development of CPM plans. The contributions are summarised as follows:

- The development of guidance for the implementation of the LPS (table 6:1).

- The development and implementation of a tool called Team Work Design (TWD), which operationalises the 8th flow and assists in the development of higher performing teams from existing ones.

- The use of pull planning to develop strategy and workflow sequencing, to aid creation of master CPM schedules.

- The study recommended training initiatives to improve the use and understanding of CPM planning by planners and supervisory staff. Furthermore, the thesis demonstrated the use of pull planning to develop master CPM schedules.

6.9 Limitations of the Study

This section discussed the limitations of the thesis. The research was limited in that it was undertaken on the refurbishment of one plant. Furthermore, the research was only applied in a large client EC organisation. Also, due to issues encountered with the CPM scheduling employed by the SC mitigated against the use of the LPS Make ready process. Additionally, the use of the LPS with TWD was not the sole initiative on the refurbishment works, with had considerably more senior management support and funding in comparison to the study.

Although the initial and later action research cycles demonstrated a positive correlation between productivity improvement and consistent percentage plan complete (PPC) of 75% and above, the study was limited in that further data needs to be collected to determine the extent of causality between consistent high PPCs achieved and positive productivity improvement gained. A further limitation was the late implementation of the TWD tool, resulting in a shortfall of continuous development of standard work in plan, do check, act cycles.

6.10 Implications for the Sponsor Company

The industrial supervisor Neil Maxfield who was Manager of Construction and is now the General Manager of capability for projects has reported the following on the 10th Dec 2016.

Initially there was slow progress in the continuation of implementation of the lean tools including the Last Planner® System (LPS) and Team Work Design (TWD) following the completion of the primary longitudinal research in March 2015. There were several reasons for this. Firstly, the research engaged a relatively small section of the workforce, no more than 400-600 people. Secondly, the contractors involved in the research had been changed almost immediately after research completion, now replaced by a new Joint Venture group of contractors.

The SC have now placed focus on collaborative planning, through continuous improvement, with site-based coaches including a superintendent who had been implementing similar approaches on off-shore projects, mobilised into the refurbishment management team. Two members of staff based at the Perth head office will support these coaches. This initiative started on Nov 28th, 2016.

There is now also a significant amount of work being done on collaborative practice and knowledge sharing within both the client and the management contractors' organisations, with significant resources and effort being applied to drive cultural change. The SC intend to be world leaders in relation to the learning culture in their organisation and their project delivery. They are undertaking this journey for the business and believe that collaborative practice is critical to achieve ongoing performance improvement in their refurbishment and construction projects. Collaborative practice including lean tools focus areas. Continuous improvement to drive sustainable performance are a focus within construction contracting. Neil believed that this will provide the momentum that was identified during the longitudinal research, with implementation by all levels of the organisation made up of the frontline workforce and support staff throughout the lifecycle of projects from concept definition/BOD phase through front end engineering development (FEED), and execute phases through to completion.

6.11 Recommendations for Future Research

This research has described the longitudinal implementation of lean tools on the refurbishment of an integrated LNG plant. The study has led to recommendations for future research

- Research into the implementation of the Exemplar LPS on EC and other projects
- Research into the outcomes of cycles of the LPS to develop robust data sets on the relation of PPC metrics and performance improvements to establish correlation and internal validity.
- Research to compare the outcomes of cost and efficiency productivity initiatives and those from the use of the lean tools.
- Further implementation and research on the embedment of the lean tools to continue the development of the manual providing guidance providing effective embedment.
- Further use of the TWD tool to demonstrate outcomes following distinct PDCA cycles.
- Research into further embedment of the tools on other EC projects in the onshore and offshore oil and gas environment.

6.12 References

Abdel-Razek, R., et al., 2007. Labor productivity: Benchmarking and variability in Egyptian projects. *International Journal of Project Management,* 25 (2), 189-197.

Adenfelt, M. and Lagerstrom, K., 2006. Enabling knowledge creation and sharing in transnational projects. *International Journal of Project Management,* 24, 191-198.

Alves, T., Milberg, C. and Walsh, K., 2012. Exploring lean construction practice, research, and education. *Engineering Construction & Architectural Management,* 19 (5), 512-525.

Andrews, P. and Brunner, E., 1955. *The Life of Lord Nuffield: A Study in Enterprise and Benevolence.* Oxford UK: Blackwell.

Ankrah, N., 2007. *An Investigation into the impact of culture on construction project performance.* Phd., University of Wolverhampton.

Archibald, R. and Villoria, R., 1967. *Network based management systems (PERT/CPM).* New York,: John Wiley.

Arditi, D., Nayak, S. and Damci, A., 2017. Effect of organizational culture on delay in construction. *International Journal of Project Management,* 35, 136-147.

Aslesen, S. and Bertelsen, S., 2008. Last planner in a social perspective - a shipbuilding case. *In: Proceedings for the 16th Annual Conference of the International Group for Lean Construction, Manchester, July.* IGLC, pp. 333-343.

AWPA, 2013. *Resources sector skills needs 2013.* Canberra: Australian Government.

Aziz, R.F. and Hafez, S.M., 2013. Applying lean thinking in construction and performance improvement. *Alexandria Engineering Journal,* 52 (4), 674-695.

Babson, S., 1993. Lean or Mean: The MIT Model and Lean Production at Mazda. *Labor Studies Journal,* 18 (2), 3-25.

Ballard, G. and Howell, G., 1997. Implementing Lean Construction: Improving downstream performance. *In:* L. Alarcon, ed., *Lean Construction.* Rotterdam: AA Balema, 1997, pp. 115-130.

Ballard, G. and Tommelein, I.D., 2016. *Current Process Benchmark for the Last Planner System.* Berkeley, CA. USA: p2sl Berkeley.

Ballard, G., et al., 2001. *Production System Design: Work Structuring Revisited LCI White Paper #11.* CA. USA: Lean Construction Institute.

Ballard, G., 2000. *The Last Planner System of Project Control.* PhD Thesis., Birmingham University UK.

Ballard, G. and Howell, G., 2003. Lean project management. *Building Research & Information,* 31 (2), 119-133.

Bartel, C. and Garud, R., 2003. *Narrative knowledge in action :Adaptive abduction as a mechanism for knowledge creation and exchange in organizations.* Malden, MA: Blackwell.

BCA, 2013. *Securing Investment in Australia's future; Report of the Project Costs Task Force.* Melbourne: Business Council of Australia.

Bechky, B.A., 2003. Sharing Meaning Across Occupational Communities: The Transformation of Understanding on a Production Floor. *Organization Science,* 14 (3), 312-330.

Berggren, C., 1993. *The Volvo experience : alternatives to lean production in the Swedish auto industry.* Basingstoke: Macmillan.

Bernold, L.E. and Tai, S.L., 2010. Experimental Research in Construction. *Journal of Construction Engineering & Management,* 136 (1), 26-35.

Bertelsen, S., 2002. Bridging the gaps: Towards a comprehensive understanding of Lean. *In: IGLC Conference, Bramado, Brazil, 2002.* IGLC, .

Bertelsen, S. and Bonke, S., 2011. Transformation, Flow, Value as a strategic tool in project production . *In: IGLC 19, Lima, Peru, July.* IGLC, pp. 1-10.

Bettinger, C., 1989. Use corporate culture to trigger high performance. *Journal of Business Strategy,* , 38-42.

Biton, N. and Howell, G.A., 2013. The journey of lean construction theory: A review and reinterpretation. *In: Proceedings IGLC-21, Fortaleza Brazil, July.* Brazil: IGLC, pp. 125-132.

Blaikie, N.W.H., 2000. *Designing social research: the logic of anticipation.* Cambridge, UK.: Polity Press.

Boisot, M., 1998. *Knowledge assets: securing competitive advantage in the information economy.* Oxford: Oxford University Press.

Bølviken, T., Rooke, J. and Koskela, L., 2014. The wastes of production in construction - a TFV based taxonomy. *In: Proceedings IGLC-22, Oslo, Norway, June.* Oslo: IGLC, pp. 811-820.

Britt, K., et al., 2014. Lessons learned from the make ready process in a hospital project. *In: Understanding and improving project based production, Oslo, Norway, June.* IGLC, pp. 257-268.

Brookes, N., 2012. What is engineering construction and why is it important? Towards a research agenda. *Construction Management and Economics,* 30 (8), 603-607.

Brookfield, R. and Cooke, J., 2011. *Modularisation: a pioneering approach.* The Petroleum Economist.

Brown, M., 2013. Ten years experience of North Sea FPSO moorings repair, removals and life extension work. *In: SPE offshore European Engineers, Aberdeen UK,* .

Brown, A.W., Adams, J.D. and Amjad, A.A., 2007. The relationship between human capital and time performance in project management: A path analysis. *International Journal of Project Management,* 25 (1), 77-89.

Bryman, A., 2012. *Social research methods.* 4th. ed. Oxford, UK.: Oxford University Press.

Burns, D., 2007. *Systemic Action Research: A Strategy for whole system change.* Bristol, UK.: The Policy Press.

Cameron, K.S. and Quinn, R.E., 2011. *Diagnosing and Changing Organizational Culture: Based on the Competing Values Framework.* San Francisco, CA, USA.: John Wiley and Sons,.

Cano, S., et al., 2015. Barriers and success factors in Lean Construction Implementation - Survey in Pilot Context. *In: IGLC 23: Global Problems- Global Solutions, Perth WA, August.* IGLC, pp. 631-640.

Carlile, P.R., 2004. Transferring, Translating, and Transforming: An Integrative Framework for Managing Knowledge Across Boundaries. *Organization Science,* 15 (5), 555-568.

Carlile, P.R., 2002. A Pragmatic View of Knowledge and Boundaries: Boundary Objects in New Product Development. 13 (4), 442-455.

Carrillo, P., Harding, J. and Choudhary, A., 2011. Knowledge discovery from post- project reviews. *Construction Management and Economics,* 29 (7), 713-723.

Carrillo, P., Ruikar, K. and Fuller, P., 2013. When will we learn? Improving lessons learned practice in construction. *International Journal of Project Management,* 31 (4), 567-578.

Casson, M., 1993. Cultural determinants of economic performance. *J. Comp. Econ.,* 17, 418-442.

Chesworth, B., 2015. Misconceptions of Lean; Why Implementation Fails. *In: IGLC 23: Global Problems- Global Solutions, Perth Aus, August.* IGLC, pp. 621-630.

Cheung, S.O., Wong, P.S.P. and Wu, A.W.Y., 2011. Towards an organizational culture framework in construction. *International Journal of Project Management,* 29 (1), 33-44.

Chinowsky, P., Diekmann, J. and Galotti, V., 2008. Social network model of construction. *Journal of Construction Engineering and Management,* 134 (10), 804- 812.

Cicmil, S. and Hodgson, D., 2006. New possibilities for project management theory: a critical engagement. *Project Management Journal,* 37 (3), 111-122.

Clark, A., 2002. Towards a science of the bio-technological mind. *International Journal of Cognition and Technology,* 1 (1), 212-213.

Coghlan, D. and Brannick, T., 2012. *Doing Action Research in Your Own Organization.* London: Sage Publications.

Cooke, B. and Capper, G., 2013. *Driving lessons in upstream Oil & Gas: Lessons from the Energy industries top performing companies.* Brisbane, Australia: PWC.

Cooke, W.N., 1994. Employee participation programs, group based incentives and company performance: A union-nonunion comparison. *Industrial and Labor Relations Review,* 47 (4), 594-609.

Coughlan, D. and Bannick, T., 2012. *Doing Action Research in your own organization.* 3rd ed. London UK: Sage Publications.

Creswell, J.W., 2009. *Research design: qualitative, quantitative, and mixed methods approaches.* 3rd ed. Thousand Oaks, Calif.: Sage Publications.

Crotty, M., 1998. *The foundations of social research: meaning and perspective in the research process.* Thousand Oaks, Calif. USA: Sage Publications.

Cummings, T.G., 1978. Self- Regulating Work Groups: A Socio-Technical Synthesis. *The Academy of Management Review,* 3 (3), 625-634.

Cusumano, M.A. and Nobeoka, K., 1998. *Thinking beyond lean: how multi-project management is transforming product development at Toyota and other companies.* New York ; London: Free Press.

Dakhli, M. and de Clercq, D., 2004. Human Capital, Social Capital, and Innovation: A Multi-country Study. *Entrepreneurship and Regional Development,* 16 (2), 107-128.

Dastmalchian, A., Lee, S. and Ng, I., 2000. The interplay between organizational culture and national cultures: a comparison of organizational practice in Canada and South Korea using the competing values framework. *International Journal of Human Resource Management,* 11 (2), 388-412.

Davis, R.C., 2007. *Shipbuilders of the Venetian Arsenal: Workers and Workplace in the Preindustrial City.* Baltimore: John Hopkins University Press.

Day, D.V., 2000. Leadership development: A review in context. *The Leadership Quarterly,* 11 (4), 581-613.

Day, D.V., Zaccaro, S.J. and Halpin, S., 2004. *Leader Development for Transforming Organisations: Growing Leaders for Tomorrow.* London: Lawrence Erlbaum and Associates.

Denzin, N. and Lincoln, Y., 2011. *The Handbook of Qualitative Research.* 4th ed. London UK: sage.

Denzin, N. and Lincoln, Y., 1994. *The Handbook of Qualitative Research.* Thousand Oaks California: Sage.

DeWalt, K., 2011. *Participant observation a guide for fieldworkers.* 2nd ed. Lanham, MD. US.: Rowman & Littlefield.

Di Vincenzo, F. and Mascia, D., 2012. Social capital in project based organisations, its role, structure and impact on project performance. *International Journal of Project Management,* 30, 5-14.

DiCicco-Bloom, B. and Crabtree, B.F., 2006. The qualitative research interview. *Medical Education,* (40), 314-332.

Diekmann, J., et al., 2004. *Application of Lean Manufacturing Principles to Construction.* Texas, USA: University of Texas at Austin.

Easterby-Smith, M., 2002. *Management research.* 2nd ed. London: Sage.

Eastman, C.M. and Sacks, R., 2008. Relative Productivity in the AEC Industries in the United States for On-Site and Off-Site Activities. *Journal of Construction Engineering and Management,* 134 (7), 517-526.

Ellis, M. and Legrand, O., 2013. *LNG Extending the Boom: Improving Australian LNG productivity and competitiveness.* Perth Australia: Mc Kinsey.

Elsborg, S. and Bertelsen, S., 2004. A Danish experiment on cooperation in construction. *In: International Group for Lean Construction, IGLC 12, Elsinore, Denmark.,* IGLC, pp 1-11.

Emiliana, M.L. and Seymour, P.J., 2011. Frank George Woollard: forgotten pioneer of flow production. *Journal of Management History,* 17 (1), 66-87.

Emiliani, M.L. and Seymour Vicarys, P.J., 2011. Frank George Woollard: forgotten pioneer of flow production. *Journal of Management History,* 17 (1), 66-87.

Eriksson, P.E., 2010. Improving construction supply chain collaboration and performance: a lean construction pilot project. *Supply Chain Management,* 15 (5), 394-403.

Eriksson, P.E. and Westerberg, M., 2011. Effects of cooperative procurement procedures on construction project performance: A conceptual framework. *International Journal of Project Management,* 29 (2), 197-208.

Farrell, P., 2011. *Writing a Built Environment Dissertation: Practical guidance and examples.* Chichester UK: Wiley-Blackwell.

Fauchier, D. and Alves, T., 2013. Last Planner System is the gateway to lean behaviours. *In: IGLC 21, Fortaleza Brazil,* IGLC, pp. 559-568.

Fayek, R., et al., 2006. Assessing Performance Trends on Industrial Construction Mega Projects. *Cost Engineering,* 48 (10), 16-21.

Fearne, A. and Fowler, N., 2006. Efficiency versus effectiveness in construction supply chains: the dangers of "lean" thinking in isolation. *Supply Chain Management,* 11 (4), 283-287.

Fellows, R., 2010. Understanding Organisational Culture in the Construction Industry. *Construction Management and Economics,* 28 (8), 898-900.

Fellows, R. and Liu, A., 2008. *Research methods for construction.* Oxford: Wiley-Blackwell.

Fernandes, N.B.L.S., et al., 2016. 24th Annual Conference of the Int'l. Group for Lean Construction. *In: Proposal for the Structure of a Standardization Manual for Lean Tools and Processes in a Construction Site, Boston, MA, USA,* pp. 103-112.

Fernandez, D. and Fernandez, J., 2009. Agile Project Management- Agilism versus traditional approaches. *The Journal of Computer Information Systems,* 49 (2), 10-17.

Fiallo, M. and Hugo- Revelo, V., 2002. Applying the last planner control system to a construction project: A case study in Quito, Ecuador. *In: IGLC-10, Gramado, Brazil,* IGLC, pp. 1-9.

Flight Centre, 2015. *Financial report for year ending June 2014.* Brisbane, Aus: Flight Centre.

Folkert, V. and Brouwer, R., 2014. Executing brownfield projects. *In: Offshore technology conference, Kuala Lumpur Malaysia,* .

Formoso, C.T. and Moura, C.B., 2009. Evaluation of the impact of the Last Planner System on the performance of Construction Projects. *In: Proceedings for the 17th Annual Conference of the International Group for Lean Construction, Salford UK,* IGLC, pp. 154-164.

Freeman, C. and Seppanen, O., 2014. Social aspects related to LBMS implementation- A case study. *In: IGLC 22 Understanding and improving project based production, Oslo, Norway, July.* IGLC, pp. 1133-1144.

Fuemana, J., Puolitaival, T. and Davies, K., 2013. Last Planner System- a step towards improving improving the productivity of New Zealand Construction. *In: Proceedings IGLC-21, Fortaleza, Brazil, July.* IGLC, pp. 679-689.

Gadde, L. and Håkansson, H., 2001. *Supply Network Strategies.* West Sussex: John Wiley & Sons Ltd.

Galloway, P., 2006. Survey of the construction industry relative to the use of CPM scheduling for construction projects. *Journal of Construction Engineering and Management,* 132, 697-711.

Gannon, M. and Banham, G., 2011. Managing knowledge in construction engineering projects. *OR Insight,* 24 (1), 17-30.

Gauthier, J. and Ika, L.A., 2012. Foundations of Project Management Research: An Explicit and Six-Facet Ontological Framework. *Project Management Journal,* 43 (5), 5-23.

Georgy, M., Chang, L. and Zhang, L., 2005. Engineering Performance in the US Industrial Construction Sector. *Cost Engineering,* 47 (1), 27-36.

Gibbert, M. and Ruigrok, W., 2010. The " What" and " How" of Case Study Rigor: Three Strategies Based on Published Work. *Organizational Research Methods,* 13 (4), 710-737.

Gibson, M., 2009. *Changing to Compete: Review of Productivity and Skills in UK Engineering Construction.* London UK: The Whitehall & Industry Group.

Gilbreth, F.B. and Gilbreth, L.M., 1922. Process charts and their place in management. *Mechanical Engineering,* 44 (1), 38-41.

Gladwell, M., 2000. *The Tipping Point.* London: Abacus.

Green, S., 2011. *Making sense of construction improvement.* Chichester: Wiley-Blackwell.

Green, S.D., 1999. The missing arguments of lean construction. *Construction Management and Economics,* 17 (2), 133-137.

Green, S. and May, S., 2005. Lean construction: arenas of enactment, models of diffusion and the meaning of 'leanness'. *Building Research & Information,* 33 (6), 498-511.

Greenwood, D. and Wu, S., 2012. Establishing the association between collaborative working and construction project performance based on client and contractor perceptions. *Construction Management and Economics,* 30 (4), 299- 308.

Habibullah, A., Lardi, P. and Passmore, M., 2009. LNG conceptual design strategies. *In: 88th GPA Annual Convention, San Antonio, Texas, March 2009.* pp. 1-15.

Hackett, V., et al., 2015. The use of first run studies to develop standard work in liquefied natural gas plant refurbishment. *In: IGC 2015: Global Problems- Global Solutions, August.* pp. 671-680.

Hackett, V., et al., 2014. Use of a pilot study to assess the development of Virtual First Run Studies (VFRS). *In: IGLC 22, Oslo Norway, June.* pp. 1331-1342.

Hamzeh, F.R., Ballard, G. and Tommelein, I.D., 2012. Rethinking Lookahead Planning to Optimize Construction Workflow . *Lean Construction Journal,* , 15-34.

Hartmann, A. and Dorée, A., 2013. Messages in Bottles: The fallacy of transferring knowledge between construction projects. *In: 29th Annual ARCOM Conference. Association of Researchers in Construction Management, Reading, UK, 2-4 September.* ARCOM, pp. 569-578.

Hegazy, T. and Menesi, W., 2010. Critical Path Segments Scheduling Techniques. *Journal of Construction Engineering & Management,* (136), 1078-1085.

Hills, L., 2014. Working Well with the Informal Leaders in Your Practice. *The Journal of Medical Practice Management : MPM,* 30 (3), 197-200.

Hodgson, D. and Cicmil, S., 2007. The Politics of Standards in Modern Management: Making 'The Project' a Reality*. *Journal of Management Studies,* 44 (3), 431-450.

Hoegl, M. and Gemuenden, H.G., 2001. Teamwork Quality and the Success of Innovative Projects: A Theoretical Concept and Empirical Evidence. *Organization Science,* 12 (4), 435-449.

Hoegl, M., 2005. Smaller teams- better teamwork: how to keep project teams small. *Business Horizons,* 48 (3), 209-214.

Hofstede, G., 2008. *Culture's Consequences: Comparing Values, Behaviors, Institutions and Organizations Across Nations.* 2nd ed. Shanghai, China: Shanghai Foreign Language Education Press.

Holweg, M., 2007. The genealogy of lean production. *Journal of Operations Management,* 25 (2), 420-437.

Hopp, W. and Spearman, M.L., 1996. *Factory Physics: Foundations of Manufacturing Management.* London: Irwin.

Howell, G. and Ballard, G., 1994. Implementing Lean Construction: Reducing Inflow Variation. *In: 2nd Annual Conference on Lean Construction, Santiago, Chile, September.* IGLC, .

Howell, G.A., 1999. What is Lean Construction. *In: Berkeley, 1999.* IGLC, pp. 1-10.

Howell, G.A., Ballard, G. and Tommelein, I., 2011. Construction Engineering-Reinvigorating the Discipline. *Journal of Construction Engineering & Management,* 137 (10), 740-744.

Howell, G.A. and Macomber, H., 2002. *A Guide for New Users of the Last Planner™ System Nine Steps for Success.* Bloomington, USA: Lean Project Consulting, Inc.

Huber, G.P., 1991. Organizational Learning: The Contributing Processes and the Literatures. *Organization Science,* 2 (1), 88-115.

Jarzabkowski, P., Bednarek, R. and Lê, J.K., 2014. Producing persuasive findings: Demystifying ethnographic textwork in strategy and organization research . *Strategic Organization,* 12 (4), 274-287.

Johnson, M., 2005. *Family, Village, Tribe: The Story of Flight Centre Limited.* Sydney, Australia: Random House.

Johnson, T. and Broms, A., 2000. *Profit beyond measure: Extraordinary results through attention to work and people, Free Press, New York.* New York: Free Press.

Jones, A., Mutch, A. and Valero-Silva, N., 2012. Exploring information flows at Nottingham City Homes. *International Journal of Information Management,* .

Jorgensen, B. and Emmitt, S., 2008. Lost in transition: the transfer of lean manufacturing to construction. *Engineering, Construction and Architectural Management,* 15 (4), 383-398.

Kalsaas, B.T., 2012. The Last Planner System Style of Planning: Its Basis in Learning Theory. *Journal of Engineering, Project, and Production Management,* 2 (2), 88-100.

Kalsaas, B.T., Skaar, J. and Thorstensen, R., 2015. Pull v Push in Construction Work Informed by the Last Planner. *In: IGLC 23 Global Problems - Global Solutions, Aug.* pp. 103-112.

Kaming, P.F., et al., 1998. Severity diagnosis of productivity problems-a reliability analysis. *Journal of Project Management,* 16 (2), 107-113.

Kerzner, H., 2006. *Project Management: A systems Approach to Planning, Scheduling and Controlling.* 9th ed. Hoboken, NJ.: Wiley.

Khan, S. and Tzortzopoulos, P., 2016. An evaluation framework for an action research study on lean design management . *In: 24th Ann. Conf. of the Int'l. Group for Lean Construction. Boston, USA,* IGLC, pp. 113-122.

Kim, Y. and Ballard, G., 2010. Management Thinking in the Earned Value Method System and the Last Planner System. *Journal of Management in Engineering,* 26 (4), 223-228.

Ko, C., Wang, W. and Kuo, J., 2011. Improving Formwork Engineering Using the Toyota Way. *Journal of Engineering, Project, and Production Management,* 1 (1), 13-27.

Kogut, B. and Zander, U., 1992. Knowledge of the Firm, Combinative Capabilities, and the Replication of Technology. *Organization Science,* 3 (3), 383-397.

Korman, R. and Daniels, S., 2003. Critics can't find the logic in many of todays CPM schedules, users want software with flexibility, but is it true CPM? *Engineering News-Rec,* 250 (20), 30-33.

Koskela, L., et al., 2016. Towards shared understanding on common ground, boundary objects and other related concepts. . *In: 24th Annual Conference of the Int'l. Group for Lean Construction, Boston, MA, USA,* IGLC, pp. 63-72.

Koskela, L., 2000. *An exploration towards a theory and its application to construction.* PhD., VTT Publications.

Koskela, L., 1993. *Application of a new production philosophy to construction.* Espoo, Finland: CIFE.

Koskela, L. and Howell, G.A., 1999. Reforming Project Management: the Role of Planning, Execution and Controlling. *In: Proceedings 7th Annual Conference of the International Group for Lean Construction, Berkeley, USA,* IGLC, .

Koskela, L. and Howell, G., 2002. The underlying theory of project management is obsolete. *In: Proceedings of the PMI Research Conference, 2002.* Project Management Institute, pp. 292-302.

Koskela, L. and Vrijhoef, R., 2001. Is the current theory of construction a hindrance to innovation? *Building Research & Information,* 29 (3), 197-207.

Koskenvesa, A., et al., 2010. Waste and labour productivity in production planning: case study in Finnish construction industry
. *In: Proceedings IGLC-18, Technion, Haifa, Israel, July.* IGLC, pp. 477-487.

Kotter, J.P., 1996. *Leading change.* Boston, Mass. USA: Harvard Business School.

Krafcik, J.F., 1988. Triumph of the lean production system. *Sloan Management Review,* 30 (1), 41-52.

Krefting, L., 1991. Rigour in Qualitative Research: The Assessment of Trustworthiness. *The American Journal of Occupational Therapy,* 45 (3), 215-222.

Lane, F., 1934. *Venetian Ships and Shipbuilding of the Renaissance. .* London: John Hopkins Press.

Larson, E., 1995. Project partnering: results of study of 280 construction projects. *Journal of Management in Engineering,* 11 (2), 30-35.

Levina, N., 2005. .Collaborating on multiparty information systems development projects: A collective reflection-in-action view. *Information Systems Res,* 16 (2), 109-130.

Levitt, B. and March, J.G., 1988. *Organizational Learning.*

Liker, J.K., 2004. *The Toyota way: 14 Management principles from the world's greatest manufacturer.* New York: Mc Graw Hill.

Lincoln, Y.S. and Guba, G., 1985. *Naturalistic Inquiry.* Beverly Hills, CA: Sage.

Liu, A.M. and Fellows, R., 2008. Organizational culture of joint venture projects: a case study of an international JV construction project in Hong Kong. *International Human Resources Development in Management,* 8, 259-270.

Liu, J., Meng, F. and Fellows, R., 2015. An exploratory study of understanding project risk management
from the perspective of national culture. *International Journal of Project Management,* 33, 564-575.

Locatellli, G. and Mancini, M., 2012. Looking back to see the future: building nuclear power plants in Europe. *Construction Management and Economics,* 8 (30), 623-637.

Love, P.E., Fong, P. and Irani, Z., 2005. *Management of Knowledge in Project Environments.* Oxford, UK.: Elsevier Butterworth Heinmann.

Luebbe, R. and Finch, B., 1992. Theory of constraints and linear programming: a comparison. *International Journal of Production Research,* 30 (6), 1471-1473.

Luecke, R., 2003. *Managing Change and Transition: 7 Practical strategies to help you through the turbulent times.* Harvard Boston: Harvard Business Press.

Lyons, T. and Skitmore, M., 2004. Project risk management in the Queensland engineering construction industry: a survey. *International Journal of Project Management,* 22 (1), 51-61.

Madter, N., et al., 2012. Exploring project management continuing professional development in engineering construction. *Construction Management and Economics,* 30, 639-651.

Malhotra, Y., 2000. Knowledge management for E- business performance: advancing information strategy to ' Internet time'. *Information Strategy: The Executive's Journal,* 16 (4), 5-16.

Mao, X. and Zhang, X., 2008. Construction process reengineering by integrating lean principles and computer simulation techniques. *Journal of Construction Engineering and Management,* 134 (5), 371-381.

Marchington, M. and Vincent, S., 2004. Analysing the Influence of Institutional, Organizational and Interpersonal Forces in Shaping Inter-Organizational Relations. *Journal of Management Studies,* 41 (6), 1029-1056.

Mays, J., 2015. *Pull Planning Lean construction* [online]. Beck Lean Committee. Available at: 5ecxE4XKrt4 [Accessed December 2015].

McCreery, J. and Murphy, B., 2014. *At the Crossroads.* Perth Australia: Oilfield Technology.

McNiff, J. and Whitehead, J., 2012. *All you need to know about action research.* 2nd ed. London: Sage Publications.

Mejía, C., et al., 2016. A Route Map for Implementing Last Planner® System in Bogotá, Colombia . *In: 4th Ann. Conf. of the Int'l. Group for Lean Construction, Boston, MA, USA,* IGLC, pp. 83-92.

Merrow, E., 2011. *Industrial megaprojects: concepts, strategies and practices for success.* New Jersey: John Wiley.

Miles, M.B. and Huberman, M., 1994. *An Expanded Sourcebook: Qualitative Data Analysis.* 2nd ed. London: Sage Publications.

Mir, F.A. and Pinnington, A.H., 2014. Exploring the value of project management: Linking Project Management Performance and Project Success. *International Journal of Project Management,* 32 (2), 202-217.

Morgan- Tuuli, M. and Rowlinson, S., 2009. Performance Consequences of Psychological Empowerment. *Journal of Construction Engineering & Management,* 135 (12), 1334-1346.

Morgan, J. and Coci, L., 2012. *Recommended Practices for the Application of LEAN Construction Methods to Building New Australian LNG Capacity.* Perth Australia: Engineers Australia.

Morris, P.W.G., et al., 2006. Exploring the role of formal bodies of knowledge in defining a profession – The case of project management. *International Journal of Project Management,* 24 (8), 710-721.

Morris, P., 2013. Reconstructing Project Management Reprised: A Knowledge Perspective. *Project Management Journal,* 44 (5), 6-23.

Mossman, A., 2012. *Last Planner collaborative conversations for predictable design & construction delivery.* Oxford: The Change Company.

Nasir, H., et al., 2012. Development and implementation of a benchmarking and metrics program for construction performance and productivity improvement. *Canadian Journal of Civil Engineering,* 39 (9), 957-967.

Nasirzadeh, F. and Nojedehi, P., 2012. Dynamic modelling of labor productivity in construction projects. *International Journal of Project Management,* 31, 903-911.

Newell, S., et al., 2009. *Managing Knowledge Work and Innovation.* New York: Palgrave Macmillan.

Nguyen, H., Lostuvali, B. and Tommelein, I., 2009. Decision analysis using virtual first -run study of a viscous damping wall system. *In: IGLC 2009, Taipei Taiwan.*

Nguyen, K., 2013. *Sharing success: Our improvements innovations and ideas.* Perth Australia: Worley Parsons.

Nicholson, N., 2000. *Executive instinct : managing the human animal in the information age.* New York: New York : Crown Business.

Nicolini, D., et al., 2012. Understanding the Role of Objects in Cross-Disciplinary Collaboration. *Organization Science,* 23 (3), 612-629.

Nonaka, I. and Takeuchi, H., 1995. *The knowledge-creating company : how Japanese companies create the dynamics of innovation.* NY. USA: Oxford University Press.

Odesola, I.A., 2015. Construction Labour Productivity as a Correlate of Project Performance: An Empirical Evidence for Wall Plastering Activity. *Civil Engineering Dimension,* 17 (1), 1-10.

Ohno, T., 1982. *Toyota Production System: Beyond Large Scale Production.* New York: Productivity Press.

Oney-Yazici, E., Arditi, D. and Uwakweh, B.O., 2006. Organizational culture in U.S. construction companies. *In: CCIM2006 Sustainable Development through Culture and Innovation, Dubai, UAE, 26–29 November 2006.* pp. 219-228.

Orlikowski, W.J., 2006. Material knowing: the scaffolding of human knowledgeability. *European Journal of Information Systems,* 15 (5), 460-466.

Özveren, E. and Yıldırım, O., 2006. *Procurement of naval supplies during the sixteenth century* . Department of Economics, Ankara: Middle East Technical University.

Paez, O., et al., 2005. Moving from lean manufacturing to lean construction: Toward a common sociotechnological framework. *Human Factors and Ergonomics in Manufacturing & Service Industries,* 15, 233-245.

Paranagamage, P., et al., 2012. Lessons learned in the UK construction sector: Lessons learned and proposed improvements. *Engineering, Project Organisation Journal,* 2 (4), 216-230.

Pasquire, C. and Court, P., 2013. An exploration of knowledge and understanding - the eight flow. *In: Proceedings IGLC-21, Fortaleza, Brazil, July.* IGLC, pp. 43-52.

Pasquire, C. and Court, P., 2012. The 8th flow - common understanding. *In: Proceedings of the 20th Annual Conference of the International Group for Lean Construction, San Diego, CA,* IGLC, pp. 1-10.

Pasquire, C.L., 2012. Positioning Lean within an exploration of engineering construction. *Construction Management and Economics,* 30 (8), 673-685.

Pescosolido, A.T., 2001. Informal Leaders and the Development of Group Efficacy. *Small Group Research,* 32 (1), 74-93.

Polanyi, M., 1966. *The Tacit Dimension.* New York: Anchor Say Books.

Polanyi, M., 1958. *Personal Knowledge: Towards a post-critical Philosophy.* Chicago: University of Chicago Press.

Polesie, P. and Frödell, M., Josephson, 2009. Implementing standardisation in medium-sized construction firms: facilitating site managers feelings of freedom through a bottom up approach implementing standardisation in medium-sized construction firms. *In: Proceedings for the 17th Annual Conference of the International Group for Lean Construction,* pp. 317-325.

Porter, S., 2007. Validity, trustworthiness and rigour: reasserting realism in qualitative research. *Journal of Advanced Nursing,* 60 (1), 79-86.

Rand, G.K., 2000. Critical chain: the theory of constraints applied to project management. *International Journal of Project Management,* 18 (3), 173-177.

Rinehart, J.R., Huxley, C. and Robertson, D., 1997. *Just Another Car Factory?* Ithaca, NY.: Cornell University Press.

Rodrigues, L. and Mackness, J., 1998. Teaching the meaning of synchronisation using simple simulation tools, . *International Journal of Operations and Production Management,* 18 (3), 246-259.

Rodríguez, D., et al., 2012. Empirical findings on team size and productivity in software development. *Journal of Systems and Software,* 85 (3), 562-570.

Rooke, J., Seymour, D. and Crook, D., 1997. Preserving methodological consistency: a reply to Raftery, McGeorge and Walters. *Construction Management and Economics,* 15 (5), 491-494.

Ross, C.A., 2014. The Benefits of Informal Leadership. *Nurse Leader,* 12 (5), 68-70.

Saldana, J., 2013. *The Coding Manual for the Qualitative Researchers.* 2nd ed. London: Sage.

Salem, O., et al., 2005. Site Implementation and Assessment of Lean Construction Techniques. *Lean Construction Journal,* 2 (9), 1-58.

Salem, O., et al., 2006. Lean Construction: From Theory to Implementation. *Journal of Management in Engineering,* 22, 168-175.

Samuelsson, P., 2006. *Integrated Measurement and the Assessment of Performance in Large Organizations: The Case of a Swedish Construction Company.* PhD thesis., Building economics and management. Department of civil and environmental engineering. Chalmers University of Technology. Göteborg, Sweden.

Santos, A., Formoso, C.T. and Tookey, J.E., 2002. Expanding the meaning of standardisation within construction processes. *The TQM Magazine.,* 14 (1), 25-33.

Schein, E.H., 2004. *Organizational Culture and Leadership*
. Third ed. London: Jossey-Bass.

Schmenner, R. and Swink, M., 1998. Conceptual note on theory in operations management
. *Journal of Operations Management,* 17, 97-113.

Seddon, J., 2003. *Freedom from Command & Control: a better way to make the work work.* Buckinghamshire, UK.: Vanguard Press.

Senge, P., 2006. *The Fifth Discipline; The Art of Practice of the Learning Organisation.* London: Random House.

Sethi, R. and Nicholson, C.Y., 2001. Structural and contextual correlates of charged behavior in product development teams. *The Journal of Product Innovation Management,* 18 (3), 154-168.

Seymour, D. and Rooke, J., 1995. The culture of the industry and the culture of research. *Construction Management and Economics,* 13 (6), 511-523.

Shadish, W.R., 2002. *Experimental and quasi-experimental designs for generalized causal inference.* Boston, USA: Houghton Mifflin.

Shadish, W., Cook, T. and Campbell, D., 2002. *Experimental and Quasi- Experimental Designs for Generalised Causal Inference.* Belmont CA: Wadsworth CENGAGE Learning.

Shewhart, W.A., 1931. *Economic control of quality of manufactured product.* New York: Van Nostrand.

Shi, J.J. and Deng, Z., 2000. Object- oriented resource - based planning method for construction. *International Journal of Project Management,* 18, 179-188.

Shimokawa, K. and Fujimoto, T., 2009. *The Birth of Lean.* Cambridge MA.: The Lean Enterprise Institute.

Simonsen, R., Thyssen, M. and Sander, D., 2014. Is Lean Construction another fading management concept? *In: IGLC 23, Oslo Norway, July.* IGLC, pp. 85-94.

Skinnarland, S. and Yndesdal, S., 2010. Exploring the development of collaboration in construction projects: a case study. *In: Proceedings IGLC-18, Technion, Haifa, Israel, July.* IGLC, pp. 356-366.

Sripriya, R., Pratap, V. and Vidjeapriya, R., 2013. Implementation of the Last Planner System in Urban Rail Transport Infrastructure. *International Journal of Systems , Algorithms & Applications,* 3 (13), 83-86.

Star, S.I. and Greismer, J.R., 1989. Institutional ecology, "translations" and boundary objects: Amateurs and professionals in Berkley's Museum of Vertebrate Zoology 1907-1939. *Soc. Stud. Sci,* 19 (3), 389-420.

Stelth, P. and LeRoy, G., 2009. Projects' Analysis through CPM (Critical Path Method). *School of Doctoral Studies (European Union) Journal,* July (1), 10-42.

Sun, J. and Zhang, P., 2011. Owner organization design for mega industrial construction projects. *International Journal of Project Management,* 29 (7), 828-833.

Taylor, F., T., 1911. *The Principles of Scientific Management.* New York: Harper & Bros.

Thomas, H.R., 2000. Schedule Acceleration, Work Flow, and Labor Productivity. *Journal of Construction Engineering & Management,* 126 (4), 261-267.

Thomas, H.R., et al., 2002. *Reducing Variability to Improve Performance as a Lean Construction Principle.* American Society of Civil Engineers.

Thomas, H.R. and Napolitan, C.L., 1995. Quantitative Effects of Construction Changes on Labor Productivity. *Journal of Construction Engineering & Management,* 121 (3), 290-296.

Thomas, H.R. and Zavrski, I., 1999. Construction baseline productivity: Theory and practice. *Journal of Construction Engineering & Management,* 125 (5), 295-303.

Toyota, 1988. *Toyota: A History of the First 50 Years, Toyota Motor Corporation,* Toyota City (Nagoya).: Toyota Motor Corporation.

Tsai, W. and Ghoshal, S., 1998. Social Capital and Value Creation: The Role of Intrafirm Networks. *Academy of Management Journal,* 41 (4), 464-476.

Tsao, C., et al., 2004. Work Structuring to Achieve Integrated Product-Process Design. *Journal of Construction Engineering and Management,* 130 (6), 780-789.

Tushman, M.L. and O'Reilly, C., 1997. *Winning through innovation : a practical guide to leading organizational change and renewal.* Boston, Mass: Harvard Business School Press.

Vrijhoef, R. and Koskela, L., 2000. The four roles of supply chain management in construction. *European Journal of Purchasing & Supply Management,* 6 (3–4), 169-178.

Wall, G., 2014. Gaining competitive edge by managing construction risk. *In: SPE Asia Pacific Oil Conference and Exhibition, Adelaide, Australia, 14-16 Oct.* SPE, pp. 1-6.

Walrus, L., 1954. *Elements of pure economics, or the theory of social wealth.* London: Allen and Unwin.

Wang, P., et al., 2009. Flow Production of Pipe Spool Fabrication: Simulation to Support Implementation of Lean Technique. *Journal of Construction Engineering and Management,* 135 (10), 1027-1038.

Weaver, P., 2007. The origins of modern project management. *In: Fourth Annual PMI College of Scheduling Conference, Vancouver, Canada, April 2007.* pp. 1-21.

Winch, G.M., 2012. Industrial Megaprojects: Concepts, Strategies and Practices for Success. *Construction Management and Economics,* 30, 705-714.

Womack, J.P., Jones, D. and Roos, D., 1990. *The machine that changed the world.* New York: Rawson Associates.

Womack, J.P. and Jones, D.T., 2003. *Lean thinking: banish waste and create wealth in your corporation.* New York: Free Press; Simon & Schuster.

Woollard, F.G., 1952a. The basic principles of mass and flow production: first instalment, *Mechanical Handling,* 39 (4), 150-154.

Woollard, F.G., 1925. Some notes on British methods of continuous production. *In: Proceedings of The Institution of Automobile Engineers, Session 1924-1925, Vol. XIX, London, 1925.* London: The Institution of Automobile Engineers, pp. 419-474.

Woollard, F.G., 1924. Morris production methods: machines and methods used by Morris Engines, Ltd., Coventry, in grinding spline shafts and gears for automobile gear boxes. *Machinery,* 24 (602), 33-38.

Yin, R.K., 2009. *Case Study Research Design and Methods.* 4th ed. London: Sage.

Young, R., 2012. *The Performance of Australian Industrial Projects: Prepared for the business council of Australia.* Australia: Independent project analysis.

Yu, H., et al., 2013. Lean transformation in a modular building company: a case for implementation. *Journal of Management in Engineering,* 29 (1), 104-111.

Zhang, Z., Waldman, D.A. and Wang, Z., 2012. A multilevel investigation of leader-member exchange, informal leader emergence and individual team performance . *Personnel Psychology,* 65 (1), 49-78.

Appendices

Semi Structured interview aide memoire

Semi Structured Interview

Scheduling and Planning. How does it work and how useful is it- revised questions?

1. What training/experience level is expected for planners?
2. Why are plans built up from job cards and work packs?
3. Is this the optimal approach?
4. Are there other approaches that could be more efficient?
5. Why use EV.
6. Is this a more cost based approach rather than a work planning one?
7. Do the performance indicators CPI and SPI produce accurate performance reporting?
8. How accurate are the schedules themselves for progress reporting. Does reporting reflect what is happening on a daily or weekly basis?
9. Is the level of detail necessary?
10. Is there an understanding of planning among supervisors and superintendents?
11. is the knowledge among PE's and managers?
12. Is primavera and CPM the best tool to use?
13. Would an end-to-end plan on the wall be useful or desirable?

Appendix WWP Sheet

Last Planner System (LPS®) Weekly Production Planning (WPP)

Project: **Week Commencing:**	**Section:**	**Labour gangs**	**No**	**Labour gangs**	**No**	**Attendance:** **Day:** **Time**
Weekly Work Plan		**PPC for week:**				✓ ✓ ☒

No	Week	Repeat	Critical	Activity Description	Person Responsible	Work that Must & Can be done prior to Release of this Activity	M	T	W	T	F	S	S	Mat	Plant	Lab	Outputs Expect	Outputs Actual	Comments (reasons for delay)	Completed